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SERVICE CONTRACT NO. 1517281

CANADIAN FORCES BASE GAGETOWN - NOx/SOx REDUCTION PROGRAM

REPORT ONE: BASELINE TEST REPORT
for tests conducted
in March of 1982

REPORT TWO: CONTINUOUS EMISSION MONITORING
AT CFB GAGETOWN
MARCH 1982

35 pp

MICROMEDIA

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CANADIAN FORCES BASE GAGETOWN - NOx/SOx REDUCTION PROGRAM

BASELINE TEST REPORT
for tests conducted
in March of 1982

REPORT FOR THE CANADIAN CENTRE FOR MINERAL AND ENERGY TECHNOLOGY (CANMET) - DEPARTMENT OF ENERGY MINES AND RESOURCES
Contract No.: 1517281 FC: 223-000000-430707-0433
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GAGETOWN BASELINE TEST REPORT

Abstract

The Canadian Centre for Mineral and Energy Technology (CANMET)- Energy, Mines and Resources Canada, with the participation of Defence Canada, and the co-operation of Environment Canada, plan to demonstrate an advanced low NOx/SOx emission concept for coal burning, using limestone injection. The demonstration is to take place at the heating plant at Canadian Forces Base Gagetown (Oromocto, New Brunswick).

This report describes baseline tests, conducted on the existing 'boiler'** at the end of March 1982, to determine efficiency and emission levels before installing new burners and a limestone injection system. The tests provided reference data against which performance of the selected new burner and limestone injection system will be compared.

Boiler efficiencies of about 84 % were experienced burning coal without limestone. When limestone, at a Ca/S ratio of 3.25, was added to the coal before pulverizing, a 35 % reduction in SO2 emissions (ppm) was experienced. Boiler efficiency dropped to 82-83 %, but this was probably due to increased ash deposition which can be controlled by sootblowing.

** For convenience the units will be referred to as boilers. However, it should be noted that they produce high temperature-hot water, not steam.

CFB GAGETOWN - LOW NOx/SOx PROGRAM - BASELINE TEST REPORT

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1.0 INTRODUCTION

Emissions of nitrogen and sulphur oxides from coal fired power plants are major contributors to acid rain and other pollution problems. Moreover, a commercial-scale demonstration of the feasibility of a combined low NOx/SOx burner system, would encourage industry to apply this technology. The fact that the proposed burner designs can be retrofitted on an existing boiler, appears to provide a feasible economic advantage over stack gas scrubbing.

G. A. Robb Associates, on behalf of EMR, provided overall co-ordination of the testing and limestone feeding from Mar. 26 through Mar. 30, the main subject of this report. Stack emissions were measured by the Pollution Measurement Division of the Air Pollution Control Directorate of Environment Canada, with all the necessary field support and service provided by Superindendent F.W. Pollitt, and the heating plant staff. G.K. Lee of EMR planned part of the test program.

2.0 TEST OBJECTIVES

(1) The 1982 baseline data was a necessary prerequiste to awarding contracts for the detailed design of a low NOx/SOx burner system and for the fabrication of an operational system at CFB Gagetown. Foster Wheeler Ltd., Steinmuller GmbH, CE Canada and B & W Canada had all expressed interest in tendering the contracts, and were present for at least part of the tests. One or more companies are to be awarded detailed design contracts with one company to be selected for the supply and retrofit of the low NOx/SOx burner system.

(2) Tests conducted between March 26th and 28th, with the boiler operating under full and half load conditions on coal only, and from March 29th to 30th, with limestone additions to the coal, provided reference data for boiler efficiency and emissions. This reference data will be used to evaluate the performance of the installed low NOx/SOx burner system. Suppliers are to guarantee emission reductions without loss in boiler efficiency, or undue consumption of limestone.

3.0 THE EXISTING FACILITIES and TEST SETUP

3.1 Existing Facility

The Gagetown heating plant consists of 3 basically identical- 70 MBTU/hr, CE Lamont controlled circulation, balanced draft hot water boilers. The installation was built in 1953 by Combustion Eng. See figure 3.1a on the following page.

Each boiler has two CE type RO, front-wall mounted, pulverized coal burners with one directly above the other. Each burner, which has its own Raymond Bowl Mill pulverizer, has a capacity of 35 million BTU/hr for a total capacity of 70 MBTU/hr (21 MW). See figures 3.1b and c.

It should be noted that a small amount of No. 2 oil (see Table 5.0c, page 19) was required to maintain flame stability. This oil input was accounted for in analysing the test results as discussed in Appendix I.

A maximum of two boilers operate during winter with one on standby.

Source:

BUSTION ENGINEERING, INC.

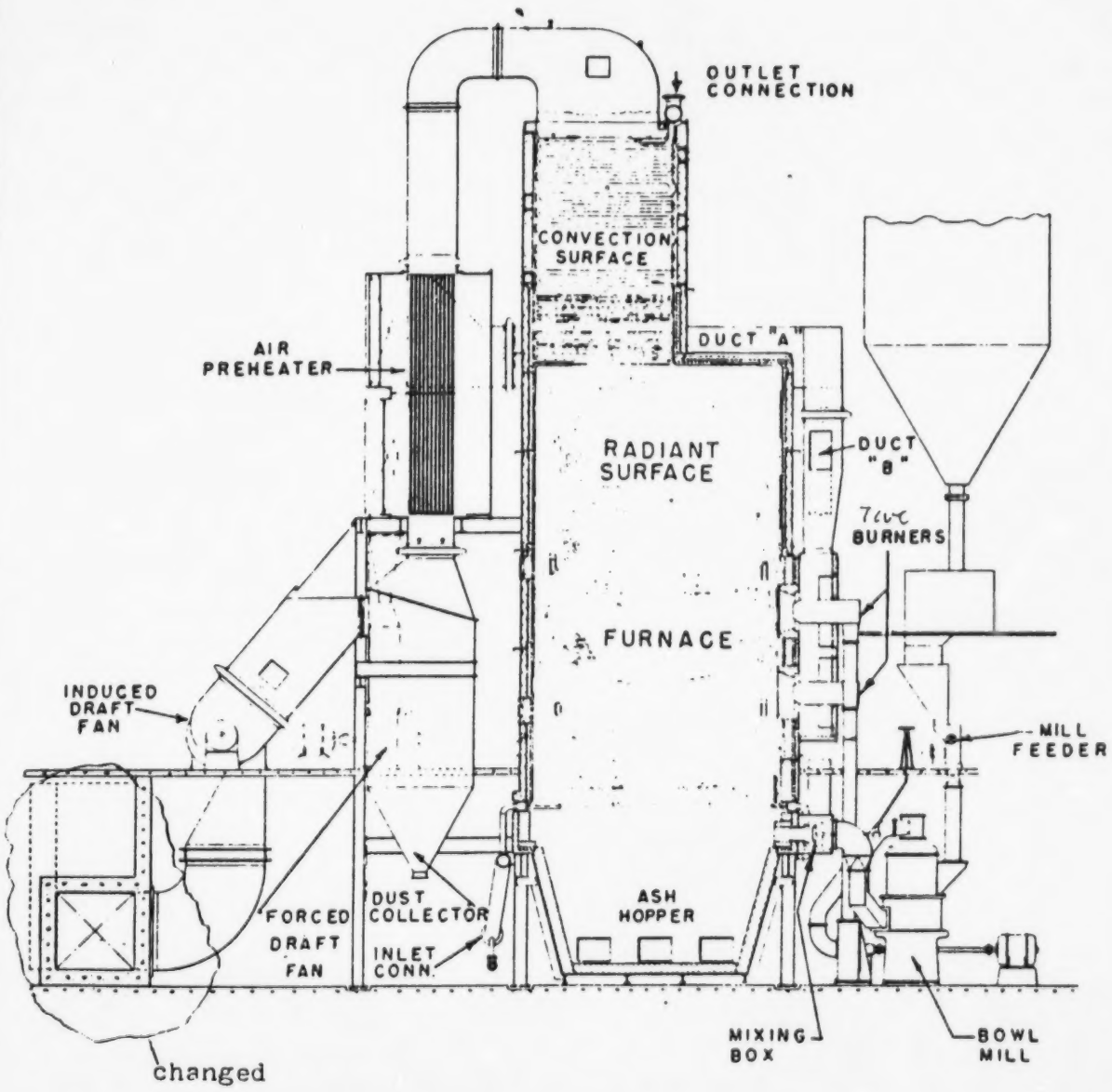


FIGURE 3.1a
EXISTING FACILITY

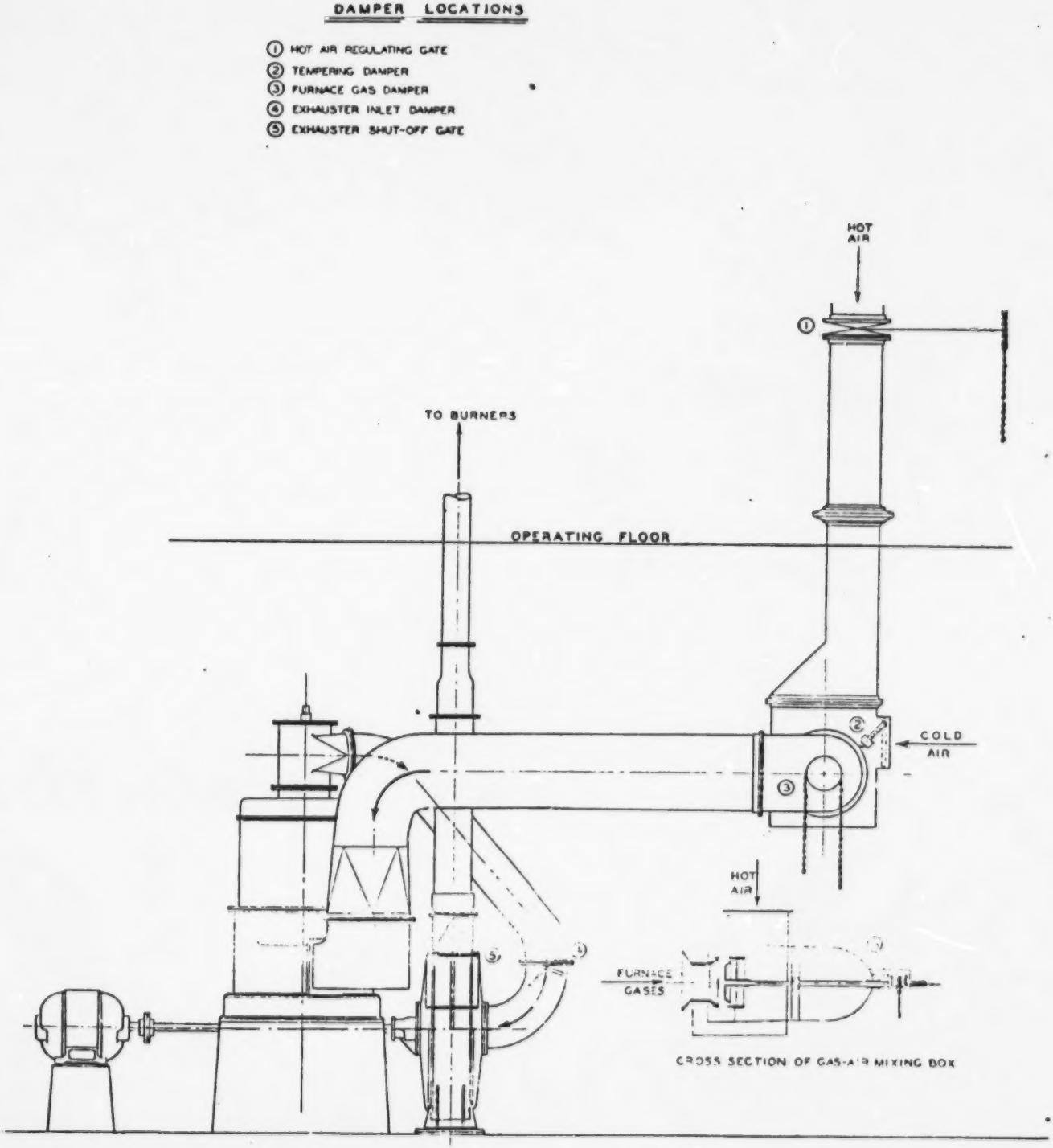


Figure 3.1b
PULVERIZER

Source:
Combustion Engineering

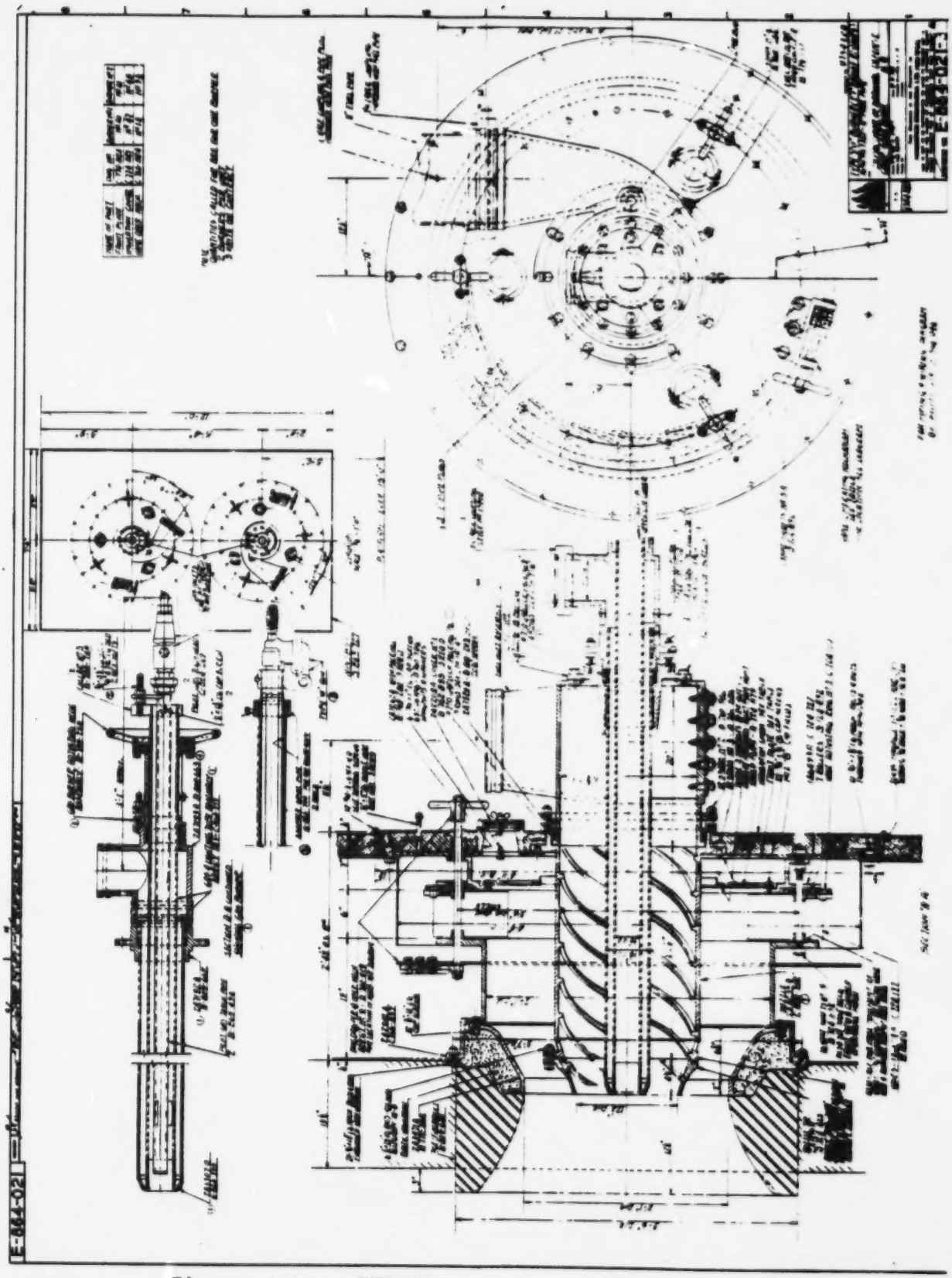


Figure 3.1e: BURNER

Source: Combustion Engineering

3.2 Test Boiler

The plan is to install the selected low NOx/SOx burner system on unit 2. Initially unit 2 was used for the baseline tests; however, due to unplanned maintenance, unit 3 had to be used from the morning of March 28th onwards. The following differences between units 2 & 3 should be noted:

(1) Unit 3 has a newer, more complex burner management system.

(2) There was leakage of air between the air heater and the Environment Canada sampling point (fig. 4.1b) before the settling chamber. (See Observations, page 15 and Discussion of Results, item 5, page 22.)

3.3 Baseline Test, Limestone Injection System

To provide some control over limestone addition, a temporary feed system was designed by heating plant superintendent F.W. Pollitt. It consisted of a small hopper and a metering orifice, which entered the coal stream just below the rotary displacement coal feeder (see figure 3.3a on the following page).

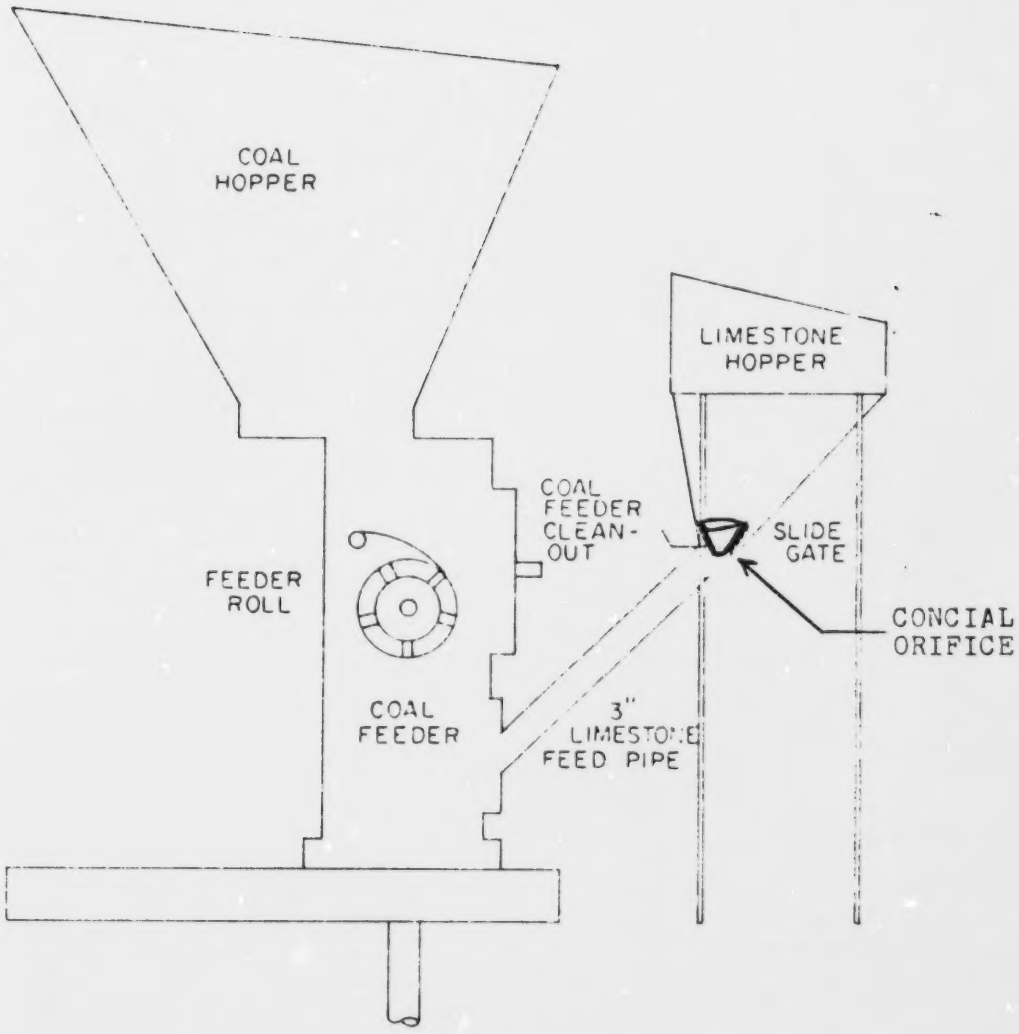


Figure 3.3a
BASELINE TEST LIMESTONE INJECTION SYSTEM

Source:
F.W. Pollitt

4.0 PROCEDURE

4.1 Test Procedures

(1) The gas flow rate was measured, while continuously monitoring NOx, SO2, O2 and CO. This allowed emissions to be stated in lbs per million BTU or mg per MJ of fuel input, and PPM. NOx, SO2, and CO readings were corrected to 3 % oxygen.

These measurements were taken in the duct connecting the test boiler to the chimney plenum (see fig. 4.1a, page 10). The temperature and O2 levels were also measured at the air heater outlet for calculation of boiler efficiency by the heat loss method.

(2) During the half load tests, only the lower burner and corresponding pulverizer were used.

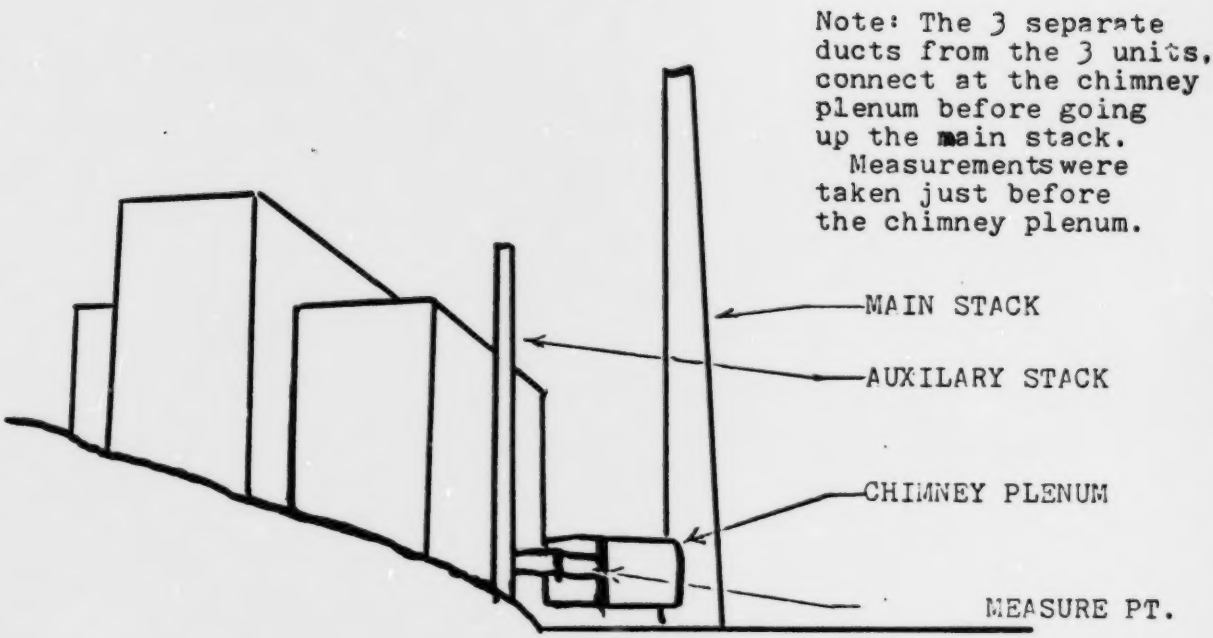

Note: The 3 separate ducts from the 3 units, connect at the chimney plenum before going up the main stack.
Measurements were taken just before the chimney plenum.
MAIN STACK
AUXILARY STACK
CHIMNEY PLENUM
MEASURE PT.

Fig. 4.1a: OUTSIDE VIEW OF PLANT AND ENVIRONMENT CANADA MEASUREMENT POINT

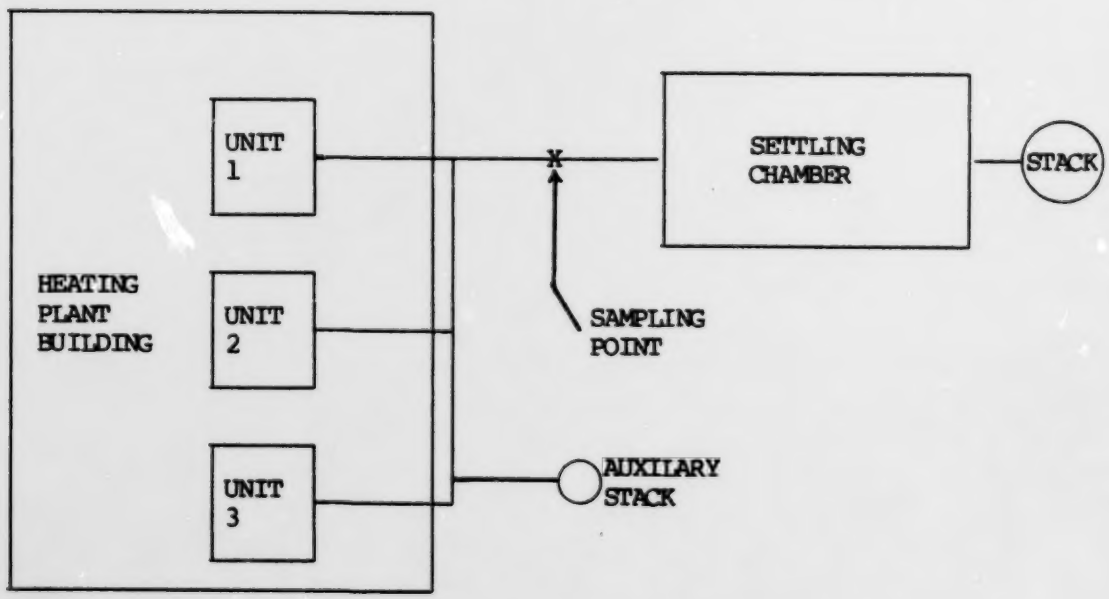


Fig. 4.1b: PLAN VIEW OF ENVIRONMENT CANADA MEASUREMENT POINT

(3) Coal samples at the pulverizer inlet and outlet were taken on alternate pulverizers every 15 minutes. One pulverizer was sampled every 30 minutes during the half load tests.

Dust collector samples were taken 15 minutes before the end of each 3 hour test, and bottom ash at the end of each test. Soot blowing was delayed until after the sampling and then hoppers were cleared for the next test.

The ash and coal was analysed by EMR/CANMET/ERL- see Appendix II.

(4) The limestone feed rate system was calibrated prior to the tests by installing different diameter orifices (see fig. 3.3a) in the hopper discharge pipe. These orifices enable the ratio of "Ca in limestone: S in coal" to be controlled. During the tests, the number of 50 lb limestone bags per unit time were counted. Thus, a good measure of feedrate was attained.

A wire mesh screen on top of the limestone hopper prevented any large pieces from plugging the measuring orifice.

4.2 Observations

DATE TEST

Mar.26 Full Load without Limestone (Morning)

Test was completed without major incident.

Mar.26 Half Load without Limestone (Afternoon)

Test was completed without major incident.

Mar.27 Half Load without Limestone (Morning)

Test was completed major without incident.

Mar.27 Half Load without Limestone (Afternoon)

Unit 2 sprung a tube leak and the test had to be aborted.

In order to identifity differences between units 2 and 3, the boiler tests without limestone were repeated March 28 on unit 3. (See "6.0 Discussion Results, item 5)

Mar.28 Full Load without Limestone (Morning)

Test was completed major without incident.

Mar.28 Half Load without Limestone (Afternoon)

Test was completed major without incident.

Mar.29 Full Load with Limestone (Morning)

Limestone feeding was started at 4 A.M, to obtain stable combustion for the test. The flow of limestone to the pulverizer which serves the upper burner was blocked. This problem was solved by removing the short 1/2 in. copper pipe, which had been welded to the bottom of the conical orifice (see fig. 3.3a) and replacing it with a 9/16 one, and, more importantly, putting a small hole in the pipe from the limestone hopper to introduce conveying air.

With the upper and lower mills having a 9/16 in. and a 1/2 in. orifice respectively, the following limestone feed rates, in lb/hr, were experienced:

Table 4.2a: Limestone Feedrates (lb/hr) (Mar. 29, A.M.)

Mill	Time (hour)		Feed Rate
	Start	Stop	lb/hr
Lower	8:00	11:00	529
Upper	8:00	10:00	970
	10:00	11:00	881
TOTAL	8:00	10:00	1499
	10:00	11:00	1410

Mar.29 Full Load with Limestone (Morning) continued

The upper mill limestone feed rate changed, despite having the same conical orifice throughout the test, because of variations in mill draft (ie.: changes in the magnitude of negative pressure in the pulverizer).

Boiler load ranged between 18.1 and 19 MW, with 11 of the 15 readings within 0.2 MW of 18.5 MW. Thus, the nominal test load was considered to be 18.5 MW.

Temperature readings of the flue gas leaving the air heater gradually increased:

Table 4.2b: Air heater Outlet Temp. (Mar. 29, A.M.)

Temp.	TIME		
	8:00h - 9:00h	9:00h - 10:00h	10:00h - 11:00h
F	486 490 495 498	498 ... 504 505	506 ... 511 516
C	252 254 257 259	259 ... 262 263	263 ... 266 269

This temperature increase was probably due to a white deposit buildup on the side and primarily on the backwall of the furnace (see 6.0 Discussion of Results, items 2).

Mar.29 Full Load with Limestone (Morning) continued

It was determined that the heating plant's Bailey temperature meter, gave a high reading for the flue gas leaving the air heater. A pyrometer, which had been checked against two Environment Canada indicators, was substituted.

As mentionned under "Sec. 3.2 Test Boiler", there was air leakage between the air heater and chimney with Unit 3. This meant that the Environment Canada oxygen readings at the chimney plenum (see fig. 4.1a, page 10) were high for the purpose of calculating boiler efficiency. The problem was resolved in the following way:

The Environment Canada O2 analyser, which measures on a dry basis, was temporarily installed at the air heater to check the Bailey O2 analyser, which measures on a wet basis. Since Environment Canada's indicator read 0.2 % lower than the Bailey analyser, the Bailey reading minus 0.2 % was used for the tests.

Mar.29 Half Load, with Limestone (Afternoon)

As with all half load tests, only the lower pulverizer and burner were used. A 1/2 in. conical orifice was again used but, this time and for the remainder tests, the small copper pipe was removed. The limestone feedrate was 801 lb/hr from 13:00 hrs to 15:00, 793 lb/hr until 15:30, and 704 lb/hr by the end of the test at 16:00. Once again variations in mill draft caused the fluctuations in limestone feedrate.

Mar.30 Full Load, with Limestone (Morning):

Limestone feeding efforts again started at 4:00 A.M. The aim was to use a 1/2 in. orifice on both mills, but limestone feeding problems forced the substitution of a 9/16 in. orifice in the upper mill till 10:00. But at 10 A.M., a 1/2 in. orifice was successfully installed in the upper mill.

Mar.30 Full Load, with Limestone (Afternoon)

The same orifices were used, and generally the same limestone feedrates prevailed as the latter part of the Mar. 30th morning test.

The following is a resume of the limestone feedrates for the two March 30th tests in lb/hr:

Table 4.2c: Limestone Feedrates (lb/hr) (March 30, A.M.)

Mill	Time (hour)		Feed Rate
	Start	Stop	lb/hr
Lower	9:00	16:00	752
Upper	9:00	10:00	881 *
	10:00	16:00	559
TOTAL	9:00	10:00	1633
	10:00	16:00	1311

NOTE: For all the limestone tests , the smoke leaving the the stack was white

* The upper mill tripped at 12:46, probably because of the increased volume it had to handle (see 5.0 Results, item 3). Other than this temporary interruption, the upper mill limestone feedrate remained fairly constant.

5.0 TEST RESULTS

The following table summarizes the baseline test results including boiler efficiency and mole ratio calculations for full load tests:

TABLE 5.0: TEST RESULTS

DAY	HOUR	UNIT	LOAD MW	% O2 <***> (+++)	NOx <mg/MJ> (ppm)	SO2 <mg/MJ> (ppm)	CO ppm	BLR EFF% *	GAS TEMP ***	Ca/S MOLE *
26	845-1145	2	20	<3.6> (3.6)	<296> (480)	<1665> (1920)	18	85.6	211 C	0
26	1442 — 1628	2	10	<3.8> (3.8)	(300)	(2100)	**			0
27	930-1230	2	9	<4.0> (4.0)	(370)	(1930)	**			0
28	845-1145	3	20.6	<4.3> (6.0)	<360> (590)	<1620> (1970)	16	84.06	240 C	0
28	1545— 1600	3	10.5	(6.2)	(420)	(1990)	26			0
29	800-1100	3	18.58	<4.74> (6.5)	<469> (720)	<1158> (1280)	1.5	82.47	260 C	3.25
29	1315— 1615	3	8.5	(7.2)	(420)	(1200)	18			N.A.
30	900-1100	3	19.68	<4.51> (6.1)	<429> (660)	<1129> (1250)	1.7	82.77	256 C	3.13
30	1405— 1550	3	19.96	<4.54> (6.3)	<459> (750)	<1131> (1330)	1.1	82.19	269 C	2.72

* The methods of calculating boiler efficiency and Ca/S ratio are in Appendix I.
** CO fluctuated too much to take proper average readings.
*** Sampling point: Where the flue gas exits the air heater.
NOx, SO2 and CO readings are corrected to 3% oxygen.
+++ Sampling point: Duct from the test boiler, just before the settling chamber.
Note: From March 26 to 27, the tests were done on unit 2.
After and including the 28th, unit 3 was used.
Test from the 29th through the 30th, involved limestone.

TABLE 5.0b: Pulverized Material Particle Size
(Percentage of particules greater than 250, 150 & 106 u in diameter.)

	% OVERSIZED		
	250 u	150 u	106 u
Pulverized Coal March 28	0.2	0.7	2.6
Pulverized Coal and Limestone March 30, AM	97.5	98.7	99.3

TABLE 5.0c: Oil Flow for Flame Stabilization

Test Conditions	DAY	Oil Flow		BTU Oil / BTU (Coal + Oil)	lb Oil / lb (Coal + Oil)
		L/hr	lb/hr		
Unit 2	26 AM	109	204.1	0.050	0.037
Unit 3	28 AM	143	267.6	0.063	0.047
" " with	29 AM	141	263.8	0.067	0.050
" " lime-	30 AM	182	340.5	0.082	0.061
" " stone	30 PM	177	331.4	0.078	0.058

6.0 DISCUSSION OF RESULTS

(1) The reductions in SOx emissions due to limestone injection were encouraging. The full load SO2 emissions, for unit 3 on March 28, were reduced by 35 % with limestone added to the coal. (See table 5.0a, page 18)

(2) Boiler efficiencies by the Heat Loss Method (considering an envelope from the air entering the air heater to the gas leaving the air heater) are shown on Table. 5.0a.

During the limestone tests, flue gas temperatures gradually increased, see Table 4.2b (page 14). The temperature increase was likely related to a white buildup on the furnace back and side walls which was easily removed by soot blowing, after termination of the tests.

This temperature increase was a factor in the drop in efficiency for the tests with limestone.

(3) Feeding limestone through the pulverizer was undesireable, as it substantially increased the top size of the pulverized material (See Table 5.0b) and caused a pulverizer to trip once on overload. Fineness is important to the sulphur absorption and combustion process.

(4) Tables 4.2a and 4.2c illustrate that limestone fed into the upper mill at two different rates. This was probably cause by fluctuations in the negative pressure in the mill which in turn changed the amount of limestone being fed into the coal stream.

It should be emphasized that limestone bags were counted and thus an accurate and independant measure of limestone feedrate was obtained.

(5) Unplanned maintenance forced a switch from unit 2 to unit 3. Hence, unit 2 was used on March 26 and 27, while unit 3 was used from the morning of March 28 onwards. One possible important difference was that:

Air leakage into the flue gas was observed between the air heater and the Environment Canada sampling point with unit 3. Possible reasons for this were the auxilary stack connected to the duct from unit 3 and holes for instrumentation which had been installed when the boiler was built. As noted under "Observations" (page 15), the problem was resolved by calbrating the heating plant's Bailey analyser against the Environment Canada O2 meter. The Bailey O2 analyser is located in the flue gas stream at the air heater outlet.

APPENDIX I

Method of Calculating Boiler Efficiency

Boiler efficiencies were determined by the heat loss method, using curves contained in the EMR CANMET publication: "A Combustion Handbook for Canadian Fuels; Volume 3.Coal.Part 1, 1974, by F.D. Fredrich and A.C.S Haden; and Volume 1 / Fuel Oil, 1969, by F.D. Fredrich".

Dry gas and moisture-hydrogen losses due to the oil and due to the coal were prorated on the basis of: 0.07 BTU of oil per BTU of the oil and coal together. The effect of limestone on efficiency was ignored.

The calculations on page 24 & 25 compare a computer calculated boiler efficiency to one using curves. Both calculations are for the morning of Mar 28 at full load on unit 3 with no limestone.

INDIRECT BOILER EFFICIENCY ANALYSIS
****

DESCRIPTION:GAGETOWN TEST: MAR 28, AM; FL; NO LIMESTONE; OIL ONLY
BOILER DESCRIPTION:UNIT 3
MAXIMUM RATING OF UNIT: 70000 LBS. OF STEAM/HOUR
: 67.9216 MBTU/HR
NUMBER OF WATER WALLS: 4
FUEL FIRED DURING TEST: 8507
ENTHALPY RISE THRU BLR.: 7.03E+07 BTU/LB
FUEL CONSTITUENTS
****

%'S BY WEIGHT

TEST	CARBON	HYDROGEN	SULPHUR	OXYGEN	NITROGEN	WATER	ASH	BTU/LB
1	86	13.3	.7	0	0	0	0	19590

TEST RESULTS
****

1 TOTAL COMBUSTION AIR= 5.45533E+09 LB/HR OR 1.2123E+09 SCFM
TOTAL H20 IN FUEL GAS= 3.59313E+08 LB/HR

*******LOSSES*******

UNBURNT FUEL	UNACCOUNTABLE	RAD. LOSS	H20 & H2	DRY GAS	TOTAL	TEST
0 %	0 %	.583327 %	7.47474 %	8.8162 %	16.8743 %	(1)

O2	EX. AIR	CO	EXHAUST. TEMP.	AMB. TEMP.	BLR. LOAD	BLR. EFF.	TEST
%	%	%	DEG. F	DEG. F	LB STM/HR	%	
4.3	24.2096	0	462	70	70000	83.12	1

INDIRECT BOILER EFFICIENCY ANALYSIS
****

DESCRIPTION:GAGETOWN TEST: MAR 28, AM; FL; NO LIMESTONE; COAL ONLY
BOILER DESCRIPTION:UNIT 3
MAXIMUM RATING OF UNIT: 70000 LBS. OF STEAM/HOUR
: 67.9216 MBTU/HR
NUMBER OF WATER WALLS: 4
FUEL FIRED DURING TEST: 0
ENTHALPY RISE THRU BLR.: 7.03E+07 BTU/LB
FUEL CONSTITUENTS
****

%'S BY WEIGHT

TEST	CARBON	HYDROGEN	SULPHUR	OXYGEN	NITROGEN	WATER	ASH	BTU/LB
1	74.8	4.9	2.6	6.3	1.4	1.5	8.5	14300

TEST RESULTS
****

1 TOTAL COMBUSTION AIR= 5.04725E+09 LB/HR OR 1.12161E+09 SCFM
TOTAL H20 IN FUEL GAS= 1.80006E+08 LB/HR

*******LOSSES*******

UNBURNT FUEL	UNACCOUNTABLE	RAD. LOSS	H20 & H2	DRY GAS	TOTAL	TEST
0 %	0 %	.583327 %	3.90177 %	8.90122 %	13.3863 %	(1)

O2	EX. AIR	CO	EXHAUST. TEMP.	AMB. TEMP.	BLR. LOAD	BLR. EFF.	TEST
%	%	%	DEG. F	DEG. F	LB STM/HR	%	
4.3	25.1509	0	462	70	70000	86.61	1

Gagetown Test Boiler Efficiency Combining Oil and Coal

Morning of March 28, Full Load, No Limestone, Unit 3

EFFICIENCY USING THE COMPUTER LISTINGS ON PREVIOUS PAGE

Overall Boiler Loss

= Oil Loss x (BTU oil input/ Total BTU input)

+ Coal Loss x (BTU coal input/ Total BTU input)

+ Unaccounted for Losses

+ Unburned Fuel Losses

$$= 16.9^{+} (0.0626)^{++} + 13.4^{+} (0.9374)^{++} + 2.6^{\ddagger} + 0^{\ddagger}$$

= 16.2 %

Overall Boiler Efficiency = 83.8 %

EFFICIENCY USING CURVES (from "A Combustion Handbook for Canadian Fuels, Vol. 3, part 1; and Vol. 1")

Oil was assumed to 7 % of the total (coal & oil) energy input.

Overall Boiler Efficiency = 84.06 % *

+See computer listings on previous page

++See Table 5.0c, page 19: Oil Flow for Flame Stablization

‡See Performance Data Sheet dated Jan. 20, 1966 (page 31)

* See Table 5.0a, page 18.

APPENDIX II

LIMESTONE ANALYSIS (AVERAGE OF 2 SAMPLES MARCH 29 AND 31)

LIMESTONE SOURCE - HAVELOCK N. B.

MOISTURE < 0.1% BY WT

ANALYSIS % BY WEIGHT

SIO2	1.8
AL2O3	0.2
Fe2O3	0.4
TiO2	0.2
P2O5	0.1
CaO	53.6
MgO	<.1
SO3	0.5
Na2O	<.1
K2O	0.1
LOF	43.0

SCREEN ANALYSIS % BY WT.

+1/4	<.1
1/4 X 6	0.1
6 x 12	28.0
12 x 20	64.2
20 x 60	6.1
69 x 0	0.6

Note: The analysis was done at the Canadian Centre for Mineral and Energy Technology (CANMET)

COAL ANALYSIS (AS FIRED AVERAGE MARCH 26,29,1982)

Coal Ultimate Analysis

Carbon	0.763
Hydrogen...	0.049
Sulphur....	0.026
Nitrogen....	0.014
Ash.....	0.085
Oxygen(by dif)	0.063
	1.000

Proximate analysis
% by weight

Moisture	1.5
Ash.....	8.5
Volatile	32.2
Fixed C	57.8

Sulphur forms

Sulphate	0.3
Pyrite	1.6
Organic (dif)	0.6

Ash Analysis
% by weight

SiO2.....	28.9
Al2O3....	15.9
Fe2O3...	32.8
TiO2d...	0.8
P2O5...	0.3
CaO....	1.5
MgO....	0.7
SO3 ...	17.3
Na2O...	0.3
K2O...	1.6

Ash fusion temp. C

	Oxidizing	Reducing
Initial ..	1345	1080
Spherical	1390	1175
Hemispherical	1400	1260
Fluid	1410	1330

Higher heating value 33,266 KJ/Kg
Hardgrove grindability 59

Screen Analysis,%by wt

+ 1 1/2	0.4	3/4 x 1/2	11.0
1 1/2 x 1	4.0	1/2 x 1/4	22.0
1 x 3/4	6.0	1/4 x 1/8	25.0

Note: The analysis was done at CANMET.

Gagetown Test

March 28, 1982
Morning, Full Load
Unit 3, No Limestone

Sample I.D: A419-82 (Bottom Ash), A420-82 (Fly Ash)

Ultimate Analysis	BOTTOM ASH	FLY ASH *
Sulphur	1.39 % (As Rec'd)	0.54 (As Rec'd)

Ash Analysis	BOTTOM ASH	FLY ASH *
Component	%	%
SiO_2	20.92	22.85
Al_2O_3	10.90	11.94
Fe_2O_3	55.45	38.52
TiO_2	0.43	0.45
P_2O_5	0.17	0.18
CaO	1.14	1.13
MgO	0.76	0.49
SO_3	3.41	1.25
Na_2O	----	----
K_2O	0.89	1.10
BaO	0.16	0.14
SrO	----	----
Mn_3O_4	----	----
LOF	6.25	21.96

Ash Fusibility (BOTTOM ASH only)

	Oxidizing		Reducing	
	F	(C)	F	(C)
Initial Deformation	2590	(1421)	2035	(1113)
Softening-Spherical	2600	(1427)	2050	(1121)
Softening-Hemispherical	2605	(1429)	2055	(1124)
Fluid	2620	(1438)	2070	(1132)

* The fly ash was collected from the cyclone hopper.

Note: The analysis was done at CANMET.

Gagetown Test

March 29, 1982
Morning, Full Load
Unit 3, Limestone

Sample I.D.: A425-82 (Bottom Ash), A423-82 (Fly Ash)

Ultimate Analysis	BOTTOM ASH	FLY ASH *
Sulphur	2.32 % (As Rec'd)	2.58 (As Rec'd)

Ash Analysis	BOTTOM ASH	FLY ASH *
Component	%	%
SIO_2	17.50	14.22
AL_2O_3	8.77	6.78
Fe_2O_3	30.82	15.21
TiO_2	0.41	0.40
P_2O_5	0.37	0.43
CaO	31.86	52.12
MgO	0.47	0.84
SO_3	7.56	6.24
Na_2O	----	----
K_2O	0.60	0.69
BaO	0.15	0.15
SrO	0.01	0.02
Mn_3O_4	----	----
LOF	1.65	3.51

Ash Fusibility (BOTTOM ASH only)

	Oxidizing		Reducing	
	F	(C)	F	(C)
Initial Deformation	2245	(1229)	2280	(1249)
Soften-Spherical	2285	(1252)	2320	(1271)
Soften-Hemispherical	2290	(1254)	2370	(1299)
Fluid	2325	(1274)	2415	(1324)

* The fly ash was taken from the cyclone hopper.

Note: The analysis was done at CANMET.

PERFORMANCE DATA SHEET

STOMER DEPARTMENT OF NATIONAL DEFENCE ~~XEC~~ No. CA-54129

No. UNITS One (1)

CATION Camp Gagetown BY DATE January 20, 1966

LER TYPE DRAWING No.

~~Supplement Sheet dated~~ By

e of Firing Coal Economizer Air Heater

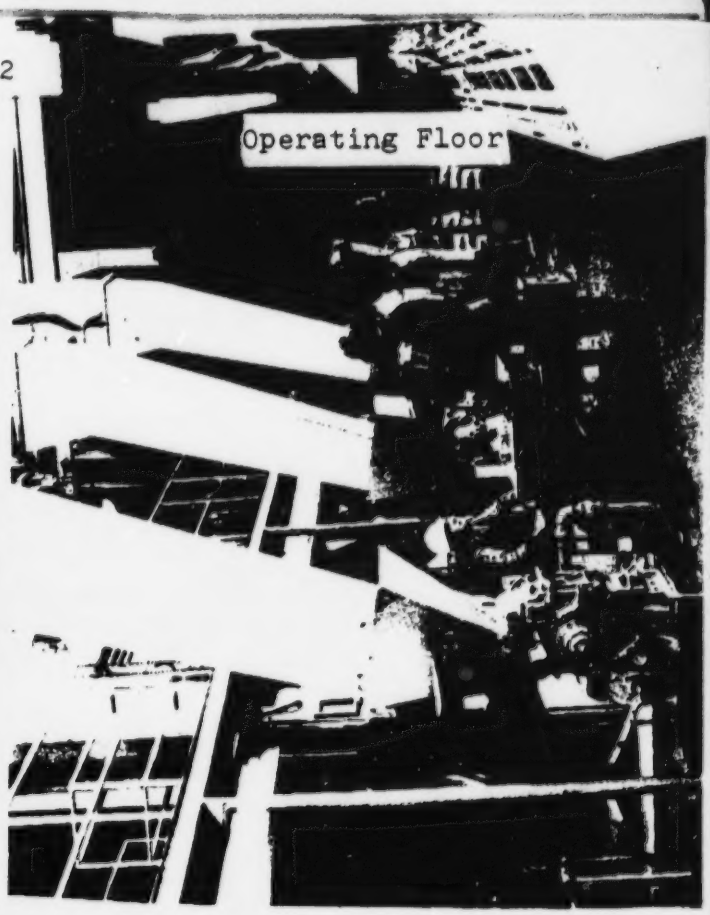
Collector Fans

, Kind Heating Value 13,229 BTU/lb.

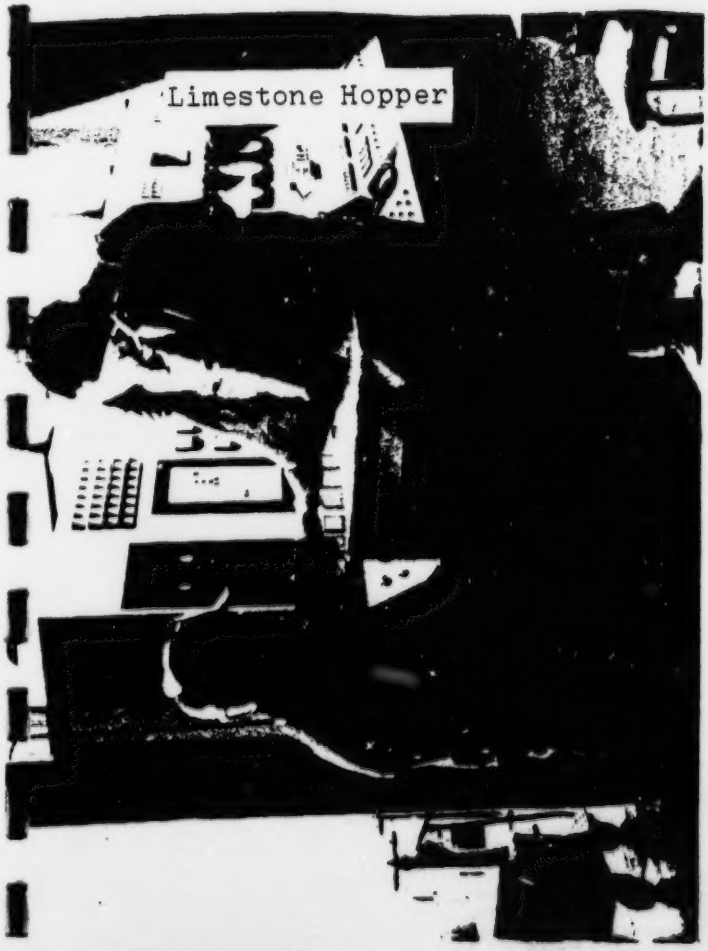
			PREDICTED	TESTED	ADJUSTED TO SPECIFIED CONDITIONS
~~Superheater~~, Water Flow		lb./hr.	594,000	813,000	813,000
Temperature at ~~superheater~~ outlet, header		deg. F.	369	371	371
Pressure at ~~superheater~~ outlet, header		psi.	160 *	154	154
Superheater pressure drop,		psi.	-	-	-
Economizer pressure drop,		psi.	-	-	-
Feedwater temperature,		deg. F.	255 *	287	287
Efficiency,		pct.	84.3*	83.6	83.8
Fuel fired,		lb/hr	6810	6380	6380
~~Superheater~~ Output	10^6 x	BTU/hr	70 *	70.7	70.7
CO$_2$, Excess air leaving,		pct.	24.0	21.3	21.3
Gas leaving,		lb./hr.			
Air leaving,		lb./hr.			
Gas temperature leaving furnace,		deg. F.	-		
Gas temperature leaving boiler,		deg. F.	655	684	684
Gas temperature leaving economizer,		deg. F.	-		
Gas temperature leaving air heater,		deg. F.	450	472	476
Feedwater temperature leaving economizer,		deg. F.	-		
Air temperature entering air heater,		deg. F.	90 *	79	90
Air temperature leaving air heater,		deg. F.	355	431	436
Draft losses: Furnace,		" wg.	0.15		
Superheater,		" wg.		-	
Boiler,		" wg.	0.20	0.21	0.21
Economizer,		" wg.		-	
Air Heater,		" wg.	0.80	1.09	1.09
Ducts,		" wg.	0.60	-	
Precipitator,		" wg.	2.60	3.20	3.20
Total,		" wg.	4.35	4.50	4.50
Air pressure losses: Burners,		" wg.	2.1	3.2	3.2
Air Heater,		" wg.	1.0	0.9	0.9
Ducts,		" wg.	0.6		
Total,		" wg.	3.7	4.1	4.1
Heat balance losses: Dry gas,		pct.	8.3	8.7	8.5
H_2O and H_2 in fuel,		pct.	4.1	4.5	4.5
H_2O in air,		pct.	0.2	-	-
Carbon,		pct.	1.0	2.6	2.6
Radiation,		pct.	0.6	0.6	0.6
Unaccounted for,		pct.	1.5	-	-
Total,		pct.	15.7	16.4	16.2
~~Extra Items: Gas Recirculation~~					
Proximate analysis of coals:		Type	Minto	Old Sydney	
Moisture		%	* 3.2 (5.0)	4.3	4.3
Volatile Matter		%	* 29.7	35.3	35.3
Fixed Carbon		%	* 47.8	51.2	51.2
Ash		%	* 19.3 (22.0)	9.2	9.2
Heating Value		BTU/lb	* 12,200	13,229	13,229
			Source:	Combustion Engineering	

Limestone Injection System

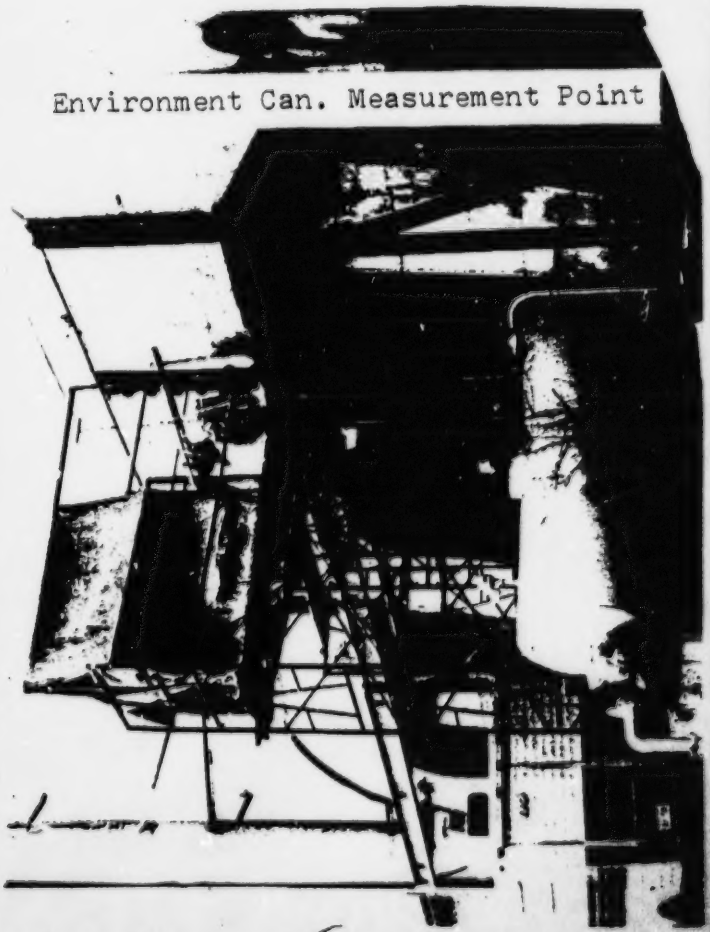
Operating Floor



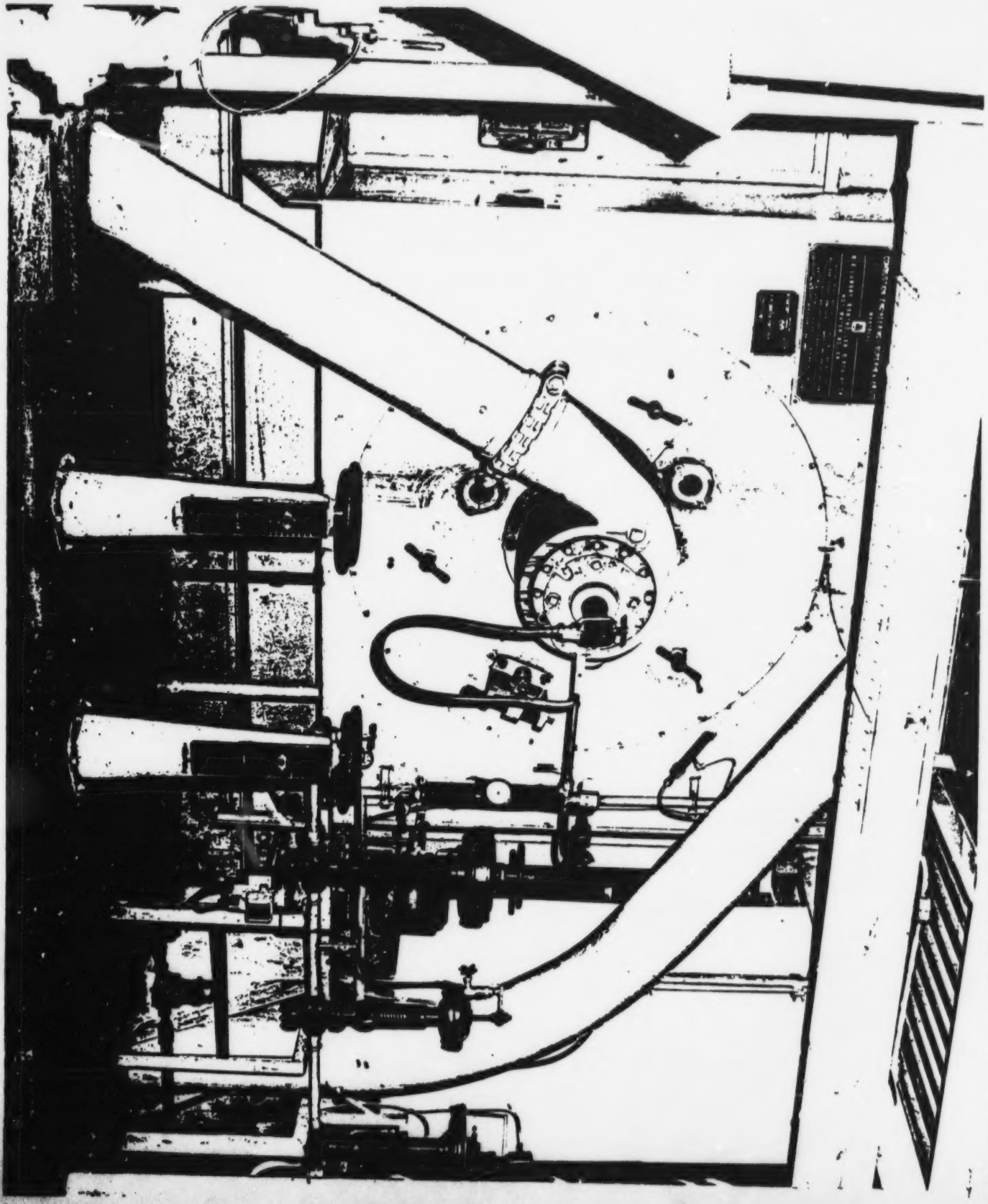
Limestone Hopper



Environment Can. Measurement Point



Front Wall Burner



CONTINUOUS EMISSION MONITORING
AT CFB GAGETOWN
MARCH 1982

ENVIRONMENT CANADA

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1. CONTINUOUS SOURCE MONITORING

The continuous monitoring system used in this study was comprised of 4 major portions as indicated in Figure 1 and below:

i) sample conditioning
ii) analytical
iii) data logging
iv) calibration

Each portion will be described separately.

1.1 Sample Conditioning

The purpose of a conditioner is to remove undesirable portions of a gas sample and feed this clean, dry sample to the appropriate analyzers without changing the concentrations of the gaseous components. The undesireable portions are normally water vapour and particulate matter, as was the case at CFB Gagetown.

Figure 2 presents the conditioning system utilized in this study.

An in-stack primary particulate filter was used to remove large diameter particulate ($>$ 10u). The gas sample was then drawn through an electrically heated $\frac{1}{4}$" Teflon sample line. This line was kept above the water dew point.

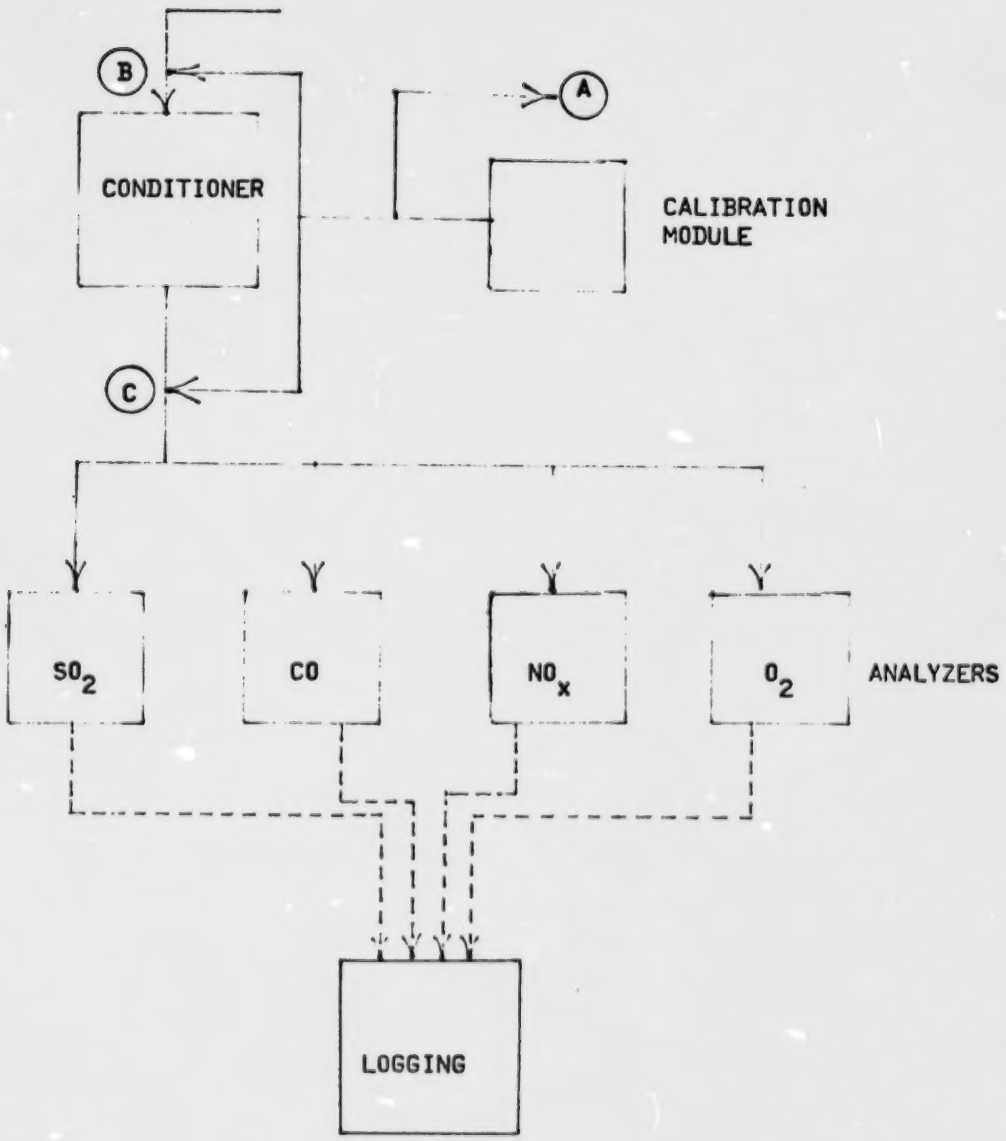
After the heated line, residual particulate matter (down to 0.3 u) was removed by a secondary filter located within a heated oven and maintained at 250°F.

The sample then entered an electrically heated pump which provided the motive force for the system.

Water was removed by forcing the sample through a stainless steel counter-flow heat exchanger, where the gases were cooled to about 50°F and subsequently had a moisture content of $\approx$1.3% (V/V). The cooling liquid was a mixture of glycol/water and this, in turn was cooled using a portable flow-through refrigeration unit. An insulated reservoir contained the fluid along with a small pump which circulated the fluid through the coolant side of the heat exchanger.

FIGURE 1

CSM SYSTEM SUB-SECTIONS

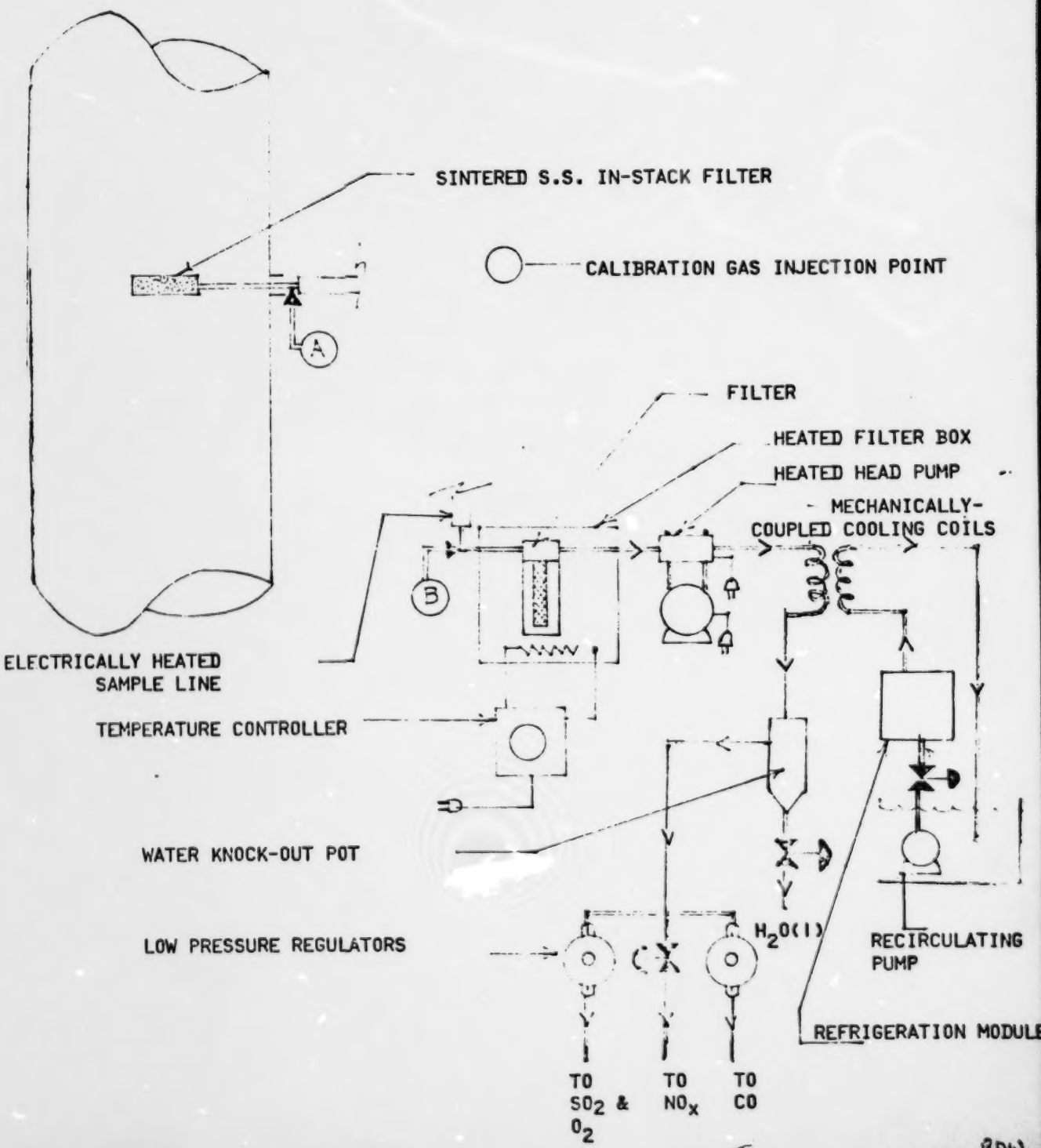


GAS

ELECTRICAL CONNECTION

FIGURE 2

SAMPLE CONDITIONING SYSTEM - CFB GAGETOWN



BDW

The gas-liquid mixture was then separated in a knock-out pot and the clean, dry sample gas distributed to the various analyzers.

As the SO_2, CO and O_2 instruments were pressure sensitive, low pressure regulators were used to supply them with gas at a constant pressure. The NO_x analyzer had a separate pump which drew only as much sample as required. Excess sample was vented to the atmosphere.

1.2 Analytical Section

Table 1 presents the analyzers utilized in this study.

TABLE I - ANALYZERS

COMPONENT	ANALYZER	RANGE UTILIZED	DETECTION PRINCIPLE
NO_x	Teco: 10AR	0-1000 ppm	Chemiluminescence
SO_2	Dupont: 411	0-2000 ppm	N.D.U.V.
CO	Bendix: 8501	0-250 ppm	N.D.I.R.
O_2	Teledyne: 320B/RC	0-25%	Polarographic

In addition, the range(s) utilized along with the detection principal are given.

1.3 Data Logging

All data from the analyzers were logged on multi-pen chart recorders. Sulphur dioxide, nitrogen oxide and carbon monoxide signals were recorded on a separate unit.

The chart speed utilized was 6 cm/hr. on both recorders.

1.4 Calibration

Compressed gas cylinders containing SO_2, NO and CO were used to calibrate the system. Table 2 gives the concentration of each standard used.

A single span gas was used for each component, as the linearity of each analyzer had been checked prior to its use.

The zero gas utilized ws ambient air, which was also used as span gas for the oxygen analyzer. The oxygen analyzer was zeroed on the SO_2 or NO tank which had only N_2 in the mixture as a major component.

Two calibration gas injection points were used, as shown in Figure 2. Injection point A provided a test for the complete system, but tended to be rather slow. Point B, found at the entrance to the secondary filter, was a much faster procedure, but excluded the heated cable in the test. A compromise was reached in which point B was normally used to calibrate, but at least once per day, gases were injected at point A.

As a minimum, all analyzers were calibrated prior to, and after each test, and at least once during the test. In the reported data, zero and span drift data were taken into account in calculating the final values.

Table 2 presents the calibration standards used in this programme. The NO (in N_2) and CO (in air) standards were analyzed by the supplier, while the SO_2 (in N_2) was analyzed by Environment Canada personnel prior to use on the survey. Additionally, the SO_2 and CO cylinders were checked against NBS cylinders (962 and 460 ppm for SO_2 and CO respectively) to verify the concentrations of the field standards.

TABLE 2 - CALIBRATION STANDARDS

COMPONENT	CONCENTRATION *
NO (in N_2)	437 ppm
CO (in air)	100 ppm
SO_2 (in N_2)	1754 ppm
O_2 (air)	20.9%

* (v/v)

2. RESULTS

Table 3 presents the results from the continuous analyzers utilized.

Mean concentrations (on a dry basis) and an estimate of the standard deviation are presented for oxygen, sulfur dioxide, nitrogen oxides and carbon monoxide. The estimates of S.D. were presented in order that users of the information could form opinions on the variation of each component being measured.

Table 4 indicating mass emission data for NO_x and SO_2, was calculated using the average stack gas parameters found during parallel particulate testing, and the average concentrations of SO_2 and NO_x presented in Table 3.

3. DISCUSSION

3.1 Sulfur Dioxide

Tables 3 and 4 show that the injection of the limestone had a beneficial action in the removal of SO_2 from the gas stream.

On a concentration basis, the SO_2 reduction was 35% at full load and 43% at half load. Using the mass emission data gives an SO_2 reduction at full load of 35%. Due to the very short duration of the March 28 test at half load on unit number 3, a particulate test was not available for velocity data. However, using the boiler load data from Table 5.0 of the G.A. Robb Associates report, an approximation of the SO_2 mass emission rate can be made. An estimate, prorated on the half load against full load data, yields a half load emission rate for SO_2 of 167 lbs/hr. Thus the % removal of SO_2 at half load is 42%.

The effect of the limestone injection on the SO_2 concentration in the gas stream is not an immediate one, as can be seen in figure 3, a photocopy of the SO_2 concentration trace during the initial limestone injection on March 29, 1982. It will be noted that over a period of 2 hours, the concentration of SO_2

CONTINUOUS MONITOR RESULTS
FROM CFB GAGETOWN (March 1982)

					OXYGEN (%)		+SO_2 (ppm)		+NO_x (ppm)		+CO (ppm)	
DATE	UNIT NO.	TEST TIMES	LOAD	LIMESTONE INJECTION	MEAN CONCENTRATION	ESTIMATE OF S.D.(S)*	MEAN CONCENTRATION	ESTIMATE OF S.D.(S)*	MEAN CONCENTRATION	ESTIMATE OF S.D.(S)*	MEAN CONCENTRATION	ESTIMATE OF S.D.(S)*
March 25	2	850-1150	Full	No	3.1	0.2	1830	19.	530	12.	19.	1.8
	2	1442-1628	Full	No	3.4	0.5	1900	21.	520	2.5	20.	1.0
March 26	2	845-1145	Full	No	3.6	0.2	1920	24.	480	14.	18.	2.1
	2	1415-1715	½	No	3.8	0.4	2100	77.	300	27.	**	
March 27	2	930-1230	½	No	4.0	0.3	1930	32.	370	20.	**	
	2	-	½	No	← (Test Terminated) →							
March 28	3	845-1145	Full	No	6.0	0.2	1970	23.	590	14.	16.	0.8
	3	1545-1600	½	No	6.2	***	1990	***	420	***	26.	***
March 29	3	800-1100	Full	Yes	6.5	0.3	1280	39	720	8.5	1.5	0.4
	3	1315-1615	½	Yes	7.2	0.4	1200	48.	420	19.	18.	1.1
March 30	3	900-1100	Full	Yes	6.1	0.3	1250	28.	660	9.4	1.7	0.9
	3	1405-1550	Full	Yes	6.3	0.2	1330	43.	750	8.8	1.1	0.2
March 31	3	1115-1304	½	Yes	7.5	0.2	1100	12.	450	3.3	25.	1.9
	3	1337-1527	½	Yes	7.2	0.3	1070	17.	410	2.8	19.	1.2

* Estimate of standard deviation (S) calculated as a guide to the variability of the source.
** Numerous occasions CO > 1000 ppm. Calculation of mean impossible.
*** Test terminated early. Too little data to calculate S.
+ Concentrations corrected to 3% oxygen.

MASS EMISSION DATA
FOR
CFB GAGETOWN (March 1982)

Date	Unit No.	Test Times	Load	Limestone Injection	Emission Rates (#/hr.)	
					SO_2	No_x (as NO_2)
March 25	2	0850-1150	Full	No	259.	54.1
	2	1442-1628	Full	No	246.	48.9
March 26	2	0845-1145	Full	No	308.	54.8
	2	1415-1715	½	No	172.	17.5
March 27	2	0930-1230	½	No	134.	18.7
	2	—	½	No	—	—
March 28	3	0845-1145	Full	No	327.	70.1
	3	1545-1600	½	No	—	—
March 29	3	0800-1100	Full	Yes	207.	83.9
	3	1315-1615	½	Yes	99.2	24.8
March 30	3	0900-1100	Full	Yes	213.	81.0
	3	1405-1550	Full	Yes	218.	88.4
March 31	3	1115-1304	½	Yes	103.	30.6
	3	1337-1527	½	Yes	88.0	23.9

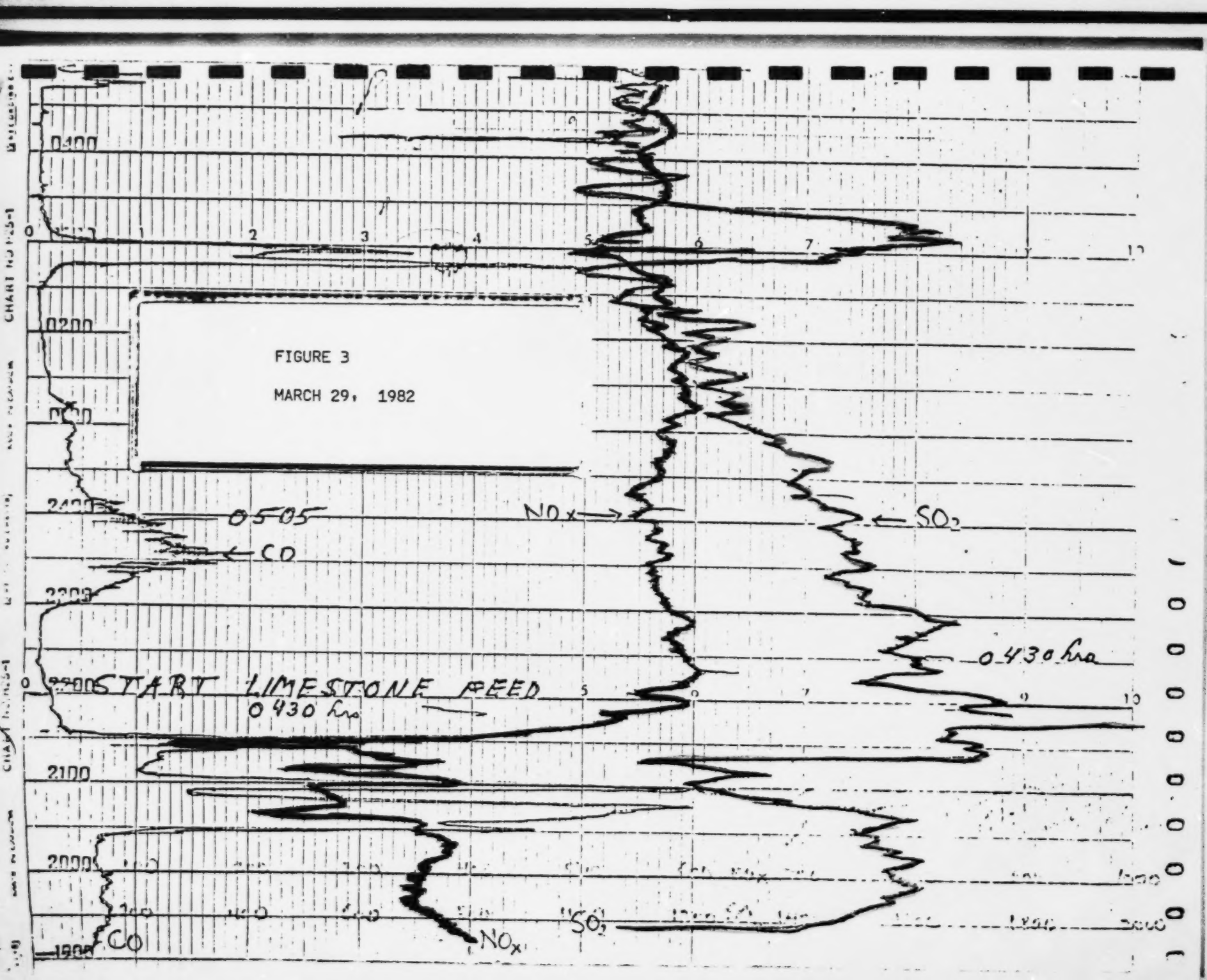


FIGURE 3

MARCH 29, 1982

gradually decreased from the initial value of about 1700 ppm to a concentration close to 1100 ppm.

3.2 Carbon Monoxide

The effect of limestone on the CO concentrations was pronounced at full load conditions where a reduction from 16 ppm without limestone to an average 1.4 ppm with limestone was noted. There was little effect of limestone injection on the CO levels at half load conditions.

3.3 Nitrogen Oxides

The effect of limestone addition on the NO_x levels at half load was minimal. At full load, there was an apparent increase in the NO_x concentration, of about 20%. Based on mass emission rates, the NO_x mass emission rate with limestone injection was also 20% greater than without injection.

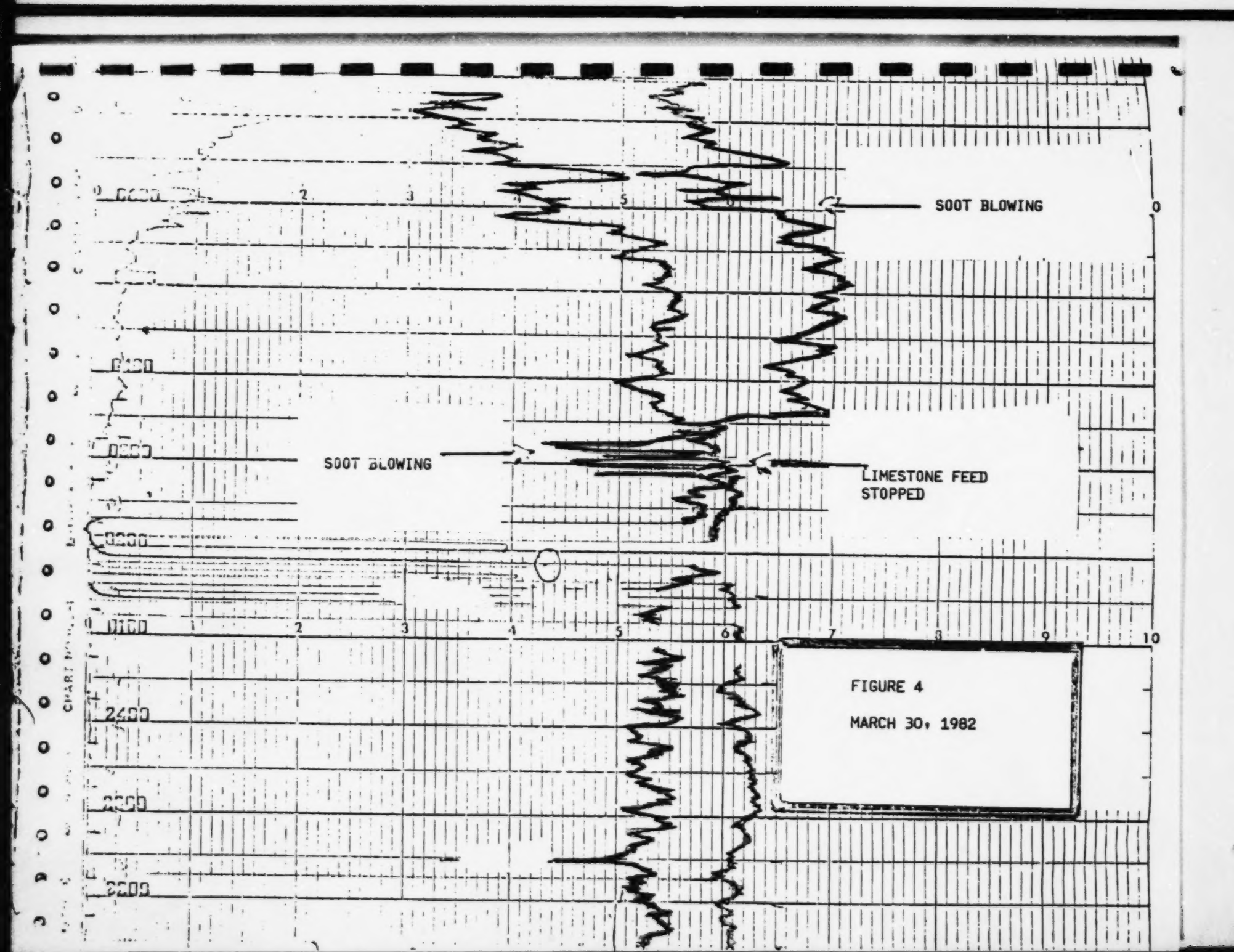
The lowering of the NO_x levels immediately following cessation of injection can be noted on Figures 4 and 5 (Blue trace).

The effect is more pronounced at the full load condition (Figure 4), but the half load test still shows an immediate and measurable decrease in NO_x concentration after limestone injection was stopped.

3.4 Effect of Particulate on In-Stack Filter

The representative of Steinmuller suggested that the build-up of limestone and other particulate on the primary filter located in the duct might cause the measured SO_2 levels to decrease due to reaction of the limestone with SO_2. Normally any particulate builds up on the leading edge of the in-stack filter until an equilibrium shape is reached depending on the stack velocity and flow patterns. The gaseous sample will not tend to try to permeate this layer to enter the filter but will entr the filter by the clear downstream portion.

Blowback on the probe filter was carried out, and no measureable difference in the SO_2 gas analysis was noted. The in-stack filter was observed and little particulate was adhering to the filter prior to or after blowback.


SOOT BLOWING
SOOT BLOWING
LIMESTONE FEED
STOPPED
FIGURE 4
MARCH 30, 1982

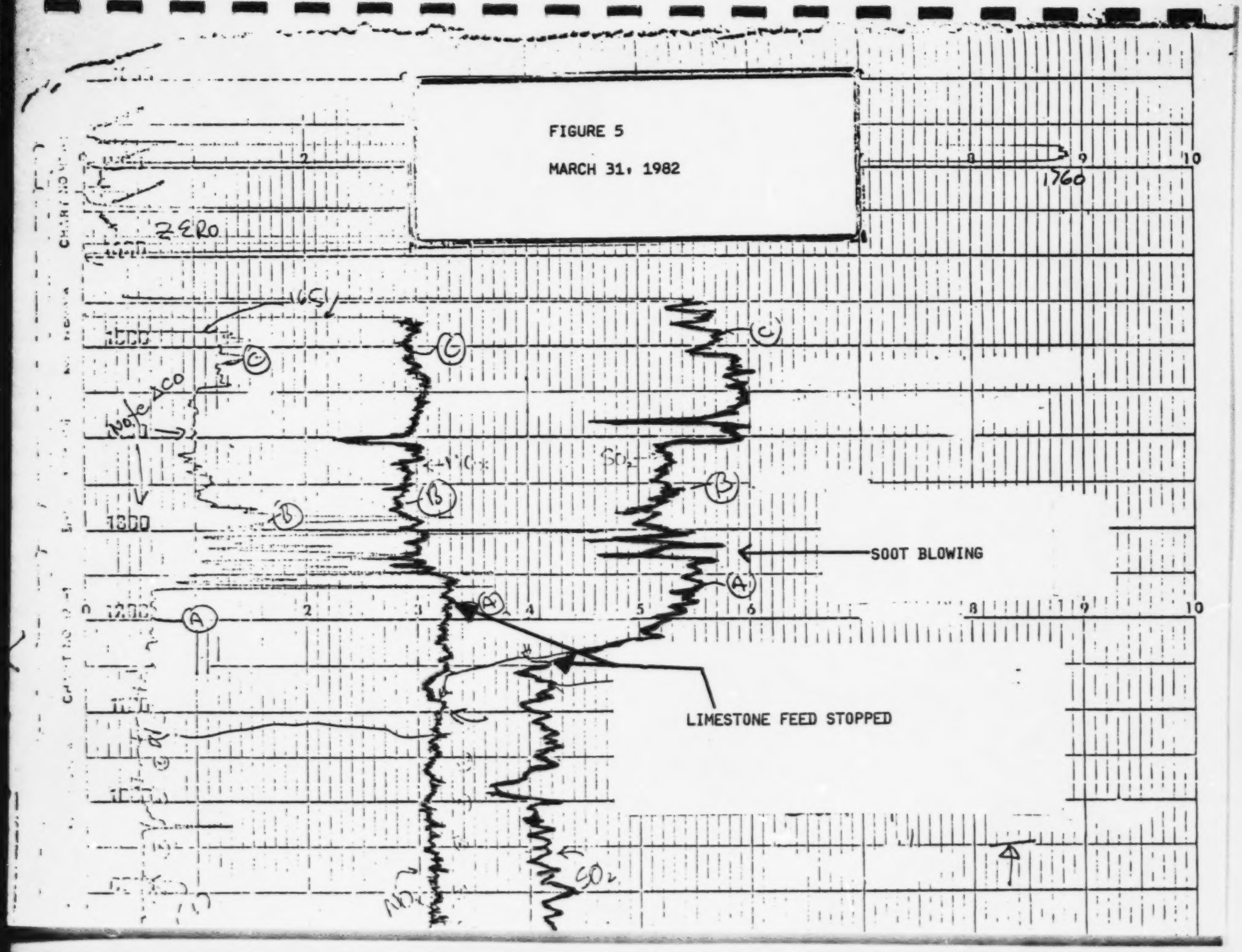


FIGURE 5
MARCH 31, 1982
ZERO
1760
1651
1800
SOOT BLOWING
LIMESTONE FEED STOPPED

4. CONCLUSIONS

1. Sulfur dioxide removal efficiencies of limestone based on concentration ranged from 35-43% depending on load, while the efficiency ranged from 35-42% based on the mass of sulfur dioxide. Removal efficiency decreased with increasing load.

2. Nitrogen oxides concentration and mass flow were not decreased by the injection of limestone, and in the case of high load, may have caused an increase in the concentration and mass flow of NO_x.

3. The injection of limestone appears to have caused a decrease in the CO concentration at full load conditions, and had little effect at half load conditions.

1-9119-1

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CANADIAN FORCES BASE GAGETOWN - NOx/SOx REDUCTION PROGRAM
TECHNO ECONOMICS

ASH HANDLING

ON SITE LIMESTONE PREPARATION VS PURCHASED LIMESTONE POWDER

COAL OPTIONS

POTENTIAL UTILITY USE

MICROMEDIA

27 pp

REPORT FOR CANMET-DEPARTMENT OF ENERGY, MINES AND RESOURCES
Contract no 1517281 FC: 223-131-000000-430707-0433
RN 23440-21-9119-1 March 28/83

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APPENDIX 2- CONTRIBUTION OF LIMESTONE TO ELECTRICAL COST

APPENDIX 3- LIMESTONE PRICE DATA

APPENDIX 4- SIEVE ANALYSIS FOR LIME DUST

ASH HANDLING AND DISPOSAL

The ash system was designed for Minto coal which has a very high ash content, as high as 20%. The coal used has an ash content of about 6%. The limestone feedrate during the baseline tests, up to 1,600 lbs of limestone per hour for about 2 hours on March 29/82 although most of that day it was 1410 lbs/hr. This corresponds with a Ca/S ratio of about 3.25. There was no evidence an ash handling problem at any point during the baseline tests. Limestone was fed at rates corresponding to full load and Ca/S ratios of roughly 3 most of the time throughout those tests involving limestone.

ASH HANDLING FACILITIES

Facilities for dealing with fly ash at Gagetown comprise a 1953 vintage Pratt Daniel mechanical collector with a hopper discharging to the pneumatic ash handling system; a large plenum adjacent to the main stack to remove some of the particulate passing through the collector and a Beaumont Birch pneumatic ash handling system. Every few hours the hoppers are emptied by opening them to the ash handling system. The amount of flyash determines the frequency of hopper clearing.

Bottom ash is racked from the furnace bottom. There were no ash handling problems experienced during the baseline tests. The ash hoppers did not fill up too rapidly. The pneumatic ash handling system emptied the system with no difficulty.

ASH DISPOSAL

In the past ash has been used for landfill. Recently it has been disposed of at the local dump. There have been discussions with the regional Environment Canada people about ash disposal when limestone is being injected. The

conclusion is that the quantity from the one boiler is too small to be a problem. Environment Canada do have some concerns about large scale disposal of ash containing sulfur compounds.

G. A. Robb Associates, particularly G. A. Robb and H. J. Barton with the help of Fred Pollitt, the station superintendent paid special attention to the ash handling system during the calibration tests of the limestone feeders and during the baseline tests. These observations are more meaningfull than any amount analysis of the system. No attempt was made to measure quantities of as during the baseline tests. Particulate loadings between the collector and the large plenum at the stack were measured. Stack emissions were not measured. It was not considered practical to measure either these or particulate loading at the furnace outlet during these tests. Too much flyash drops out in the plenum after the point of measurement for the measurements to be indicative of stack emissions.

If Novaco develops a new mine at Springhill and that coal has more ash than Sydney coal, the load on the ash system would increase but that situation should not be faced until it arises. The Novaco coal used in the 82/83 season was from a surface mine. The ash in the underground mine may be lower and there is doubt as to when and whether the mine will be developed.

The conclusion is that upgrading of the ash handling system is not justified.

ON SITE LIMESTONE PREPARATION VS PURCHASE OF POWDER.

Havelock Lime produces a wide range of limestone products

HAVELOCK LIME PRODUCTS

Crushed (but not dried) material, screened to a sizes ranging from 1.25" or less to 0.25 - 0.5 costs between $9.20 and $9.60 per tonne Havelock. The size classifications for this material are; 1.25"or less; 1.25" to 0.75"; 0.75" to 0.25"; 0.625" to 0.25" and 0.5" to 0.25". The cost at the quarry of material 0.25 or less is $5.60. This material contains dust and is difficult to handle when wet. The material which has not been dried cannot be handled pneumatically. Transportation by dump truck to Gagetown would cost about $8.60 per tonne. Thus the delivered cost the CRUSHED, UNDRIED material would be;

$17.80 to $18.20 in the 1.25" to 0.25" ranges

$14.20 for 0.25 or less including dust

Costs for material which has been screened and dried for pneumatic handling and delivery by tank truck are as follows;

6-16 mesh $20.20 material + $14 transportation = $34.20
16 or less $15.69 material + $14 transportation = $29.69

16-100 mesh $17.60 material + $14 transportation = $31.60
100 or less $23.80 material + $14 transportation = $37.80

The 100 or less material with a delivered cost of $37.80 (say $38) is produced by screening, drying, pulverizing and air classification. A test by an independent lab. indicates that 79.1% by weight passed through a 335

mesh screen.

Calcined lime (calcium oxide) is available from Havelock at $69 per tonne plus $14 transportation or a delivered cost of $83 per tonne. Oil for the calcining kiln accounts for a large fraction of this cost.

CALCIUM HYDROXIDE is available from Havelock at a delivered cost of 70 + 14 = $84 per ton.

HAVELOCK LIME FACILITIES

Havelock are a locally owned, owner managed business founded in 1938 by the Alward Family. It is still owned an operated by that family. G. A. Robb Associates have visited the Lime Works and were favourably impressed. They provided good service during the baseline tests and are providing limestone for the DND fluidized bed boiler at Summerside.

Havelock Lime operate at the Canada Cement Quarry. Most of the product is high calcium limestone with 95 to 98% calcium carbonate. They are equipped to, crush, kiln dry, screen, pulverized, air classify, and calcine limestone. They can produce hydrated lime.

Crushed limestone, screened but not dried can be delivered by dump truck at about $19/tonne ($10 for material and $9 for trucking). This material is used for road building etc. There is no quality control in terms of minimum calcium carbonate content. Crushed limestone @.25" or less is available at the quarry for $6/tonne for material and would cost $15 per tonne delivered.

The material available at $15 per tonne contains a lot of dust and is difficult to handle when wet. The study is based on the assumption that the $19 per tonne material is the alternative to buying limestone powder suitable for use

with no further treatment.

Of the standard products Havelock can supply, the material fine enough so that according to an independent lab test, 79% will pass through a 325 mesh screen would appear to be suitable for injection with the low NOx burners. According to that test, 92.7% passed through a 200 mesh screen. The cost is about $38 per ton delivered by tank truck capable of pneumatic unloading to a level 60 feet above the truck.

This material is guaranteed to be more that 90% calcium carbonate and normally is 95 to 98% calcium carbonate. It is produced by crushing, screening, kiln drying, pulverizing and air classification. Havelock have a Cedar Rapids Hammer Mill and a Sturtevant Air Classifier. The screening produces 4 different sizes. Only the smallest is pulverized.

The fact that they have markets for all the different sizes of material, and can maintain a high capacity factor on the equipment provides Havelock with major advantages visa vis on site preparation. Havelock say the cost of the pulverizer and air classifier is between $700,000 and $1,000,000.

CFB Gagetown uses about 16,000 tonnes of coal per year. There is a plan to shut the plant down for the summer months and meet warm weather heat requirements in other ways. This would reduce the coal demand by perhaps 1,000 tonnes per year but this analysis is based on 16,000 tonnes per year of 26 million BTU/ton or 30 GJ/tonne coal.

Appendix 1 is a tabulation of weight units of limestone per unit of coal assuming the limestone is 90% calcium carbonate at various Ca/S mole ratios. At a Ca/S ratio of 3, with 3% sulphur coal, 0.31 tonnes of limestone are required

per tonne of coal. The same coal would require 0.21 tonnes of limestone per ton of coal at a Ca/S ratio of 2.

COST WITH PUCHASED POWDER

Assuming the purchase of powdered limestone without any on site preparation the annual limestone costs would be as follows;

0.31 x 16,000 x $38 = $188,480 with a Ca/S ratio of 3
0.21 x 16,000 x $38 = $127,680 with a Ca/S ratio of 2

COST WITH CRUSHED LIMESTONE

If crushed limestone via dump truck were purchased at a delivered cost of $19/tonne, The annual limestone cost would be;

0.31 x 16,000 x $19 = $94,240 with a Ca/S ratio of 3
0.21 x 16,000 x $19 = $63,840 with a Ca/S ratio of 2

The reduction in cost for limestone due to buying crushed limestone for onsite preparation would be;
188,480 - 94,248 = $94,232/yr at Ca/S = 3
127,680 - 63,840 = $63,840/yr at Ca/S = 2

The figures for the Ca/S ratio of 2 should be used because if that is the most likely level of initial operation. If the Ca/S of ratio of 3 is used in the future, the equipment for on site preparation could be bought at that time if there is justification.

FINANCIAL ANALYSIS

The analysis should consider the time value of money but a simple payback analysis provides some guidance. If the capital cost of the equipment for on site preparation is $700,000, tne simple payback at the Ca/S = 2 level would be $700,000/$63,840 = 11 years. This does not consider

operating costs for the on site equipment. Thus the simple payback period would be more than 11 years.

With a simple payback of more than 11 years, the investment in on site preparation equipment clearly is not justified.

The internal rate of return over a 15 year period assuming a $700,000 initial outlay is only 0.054 or 5.4%. The present value of the stream of savings ($63,840 per year) over a 15 year period discounted at 10% is $499,000. This compares with the estimated minimum initial outlay of $700,000.

The internal rate of return (discounted cash flow rate of return) is the discount rate which equates the present value of the cash stream to the initial outlay. It must be more than the outlay could earn in another use before the the investment is justified. If the on site preparation equipment could be installed for $499,000 the IRR would be 10% if operating costs could be ignored. They cannot. In any case 10% is not enough for this sort of investment under current conditions.

There are a number of reasons for not investing in onsite preparation equipment. Calcium hydroxide is a possible alternative to limestone as a sorbent. The on site preparation equipment would be used only in winter. Havelock use their pulverizer and air classifier to produce product for general industrial and agricultural use throughout the year. Thus, they can produce the product at lower cost because the annual fixed cost is spread over far more units. While the on site option could be used as a bargaining lever in negotiating the limestone price, Havelock will always be in a position to price the product at less than it would cost to prepare it on site.

COAL OPTIONS

Assuming the options are using eastern Canadian Coal or US coal with a sulphur content of 3% with limestone injection at a Ca/S ratio of 3/1 for SOx reduction; 6% eastern Canadian coal and the same Ca/S ratio or, alternatively, 0.5% sulphur coal from either eastern USA or Western Canada with no limestone, the technical and economic considerations are as follows;

LIMESTONE REQUIREMENT

Coal containing 3% sulphur would require 0.3121 tonnes of limestone per tonne of coal to achieve a 3/1 Ca/S mole ratio. CFB Gagetown has been using about 16,000 tonnes of 26 million BTU/ton or 30 GJ/ton Devco coal. For the winter of 1982/83 the base used about 18,500 tons of 22 million BTU/ton or 26 million GJ/tonne NOVACO coal per year.

For the coal with 3% sulfur, assuming a limestone cost of $38 per tonne, the limestone cost would be 16,000 x 38 x 0.3121 = $189,757 per year.

PREMIUM FOR LOW S COAL

The cost differential between 3% sulphur US bituminous coal and US coal guaranteed to contain less than 1% sulfur is about $7 per ton. Thus the additional cost of using low sulfur coal would be 7 x 16,000 = $112,000. Low sulfur US bituminous low sulfur coal would cost less than 3% S US coal if the Ca/S ratio is 3.

With 6% sulfur coal the annual limestone cost would be 16,000 x 38 x 0.6121 = $372,156 per year with a Ca/S ratio of 3. If Minto coal with 6% sulfur could be delivered to CFB Gagetown for 372,156/16,000 = $23.25/ton less than the cost

of low sulphur coal, the annual cost of coal + limestone would be less than the cost of low sulfur coal without limestone.

According to NewBrunswick Coal, operators of the Minto Mine, Minto coal could be purchased at about $55/tonne and trucked to CFB Gagetown for $7/tonne. Thus the delivered cost would be about $62/ton.

UNITED STATES BITUMINOUS COAL

The Atlantic provinces have never taken advantage of the opportunity to use U. S. bituminous coal despite ready access to that fuel. There is a large coal flow from east coast ports to Europe and other destinations. The U. S. coal industry now concentrates on large long term utility contracts.The spot market from which coal for Gagetown would come, is now relatively small and somewhat volatile. Prices can increase because of a few large utility purchases. Most price information is either in U. S. dollars per short ton or in cents per million BTU. Available price information applies to large contract or spot purchase. While prices used in this report were discussed with brokers handling small quantities, none of them are involved in the sale of U. S. coal to Atlantic Canada because none is sold there. There is uncertainty as to what prices would actually apply for such a small quantity.

All U. S. Utilities are required to file fuel prices with the energy Regulatory Commission and they are made public. Coal Week and Coal Week International publish a great deal of price information, generally with sulfur levels, ash levels and higher heating values. A broker selling U. S. coal will present the buyer with a spread sheet with characteristics and prices of a great variety of coals with different ash fusion temperatures, grindability, sulfur, ash and heating value.

For purposes of this report it has been assumed that the ash content, heating value, and other quality characteristics of the 3% sulfur U. S. coal are the same as that of Devco coal. This simplifying assumption eliminates the need to consider quality.

U. S. Bituminous coal in the 2 to 3% S range can be bought at Hampton Roads for about $45-$50/tonne Canadian. Allowing $5/tonne for handling at Hampton Roads, $5 for handling at St. John and $10 for transportation from Hampton Roads to St. John, the cost of U. S. Bituminous coal with 3% sulfur or less would be about $65-$70/tonne Cdn at St John. Assuming the premium for coal with a sulfur content guaranteed to be less than 1% but normally about 0.5% would be about $7/tonne,the delivered cost of low sulfur coal would be about $72-$77/tonne Cdn. at St. John.

The quantity of coal used at CFB Gagetown is very small relative to quantities to which available price/cost information applies. A premium must be added to account for that. Assuming a cost of $15/ton for delivery to CFB Gagetown and a premium of $10 per ton to account for the small quantity,the low end of the range delivered cost at CFB Gagetown would be $97 per ton. This would leave $97 - $62 = $35/ton to pay for limestone.

COST WITH MINTO COAL AND LIMESTONE
Annual cost with Minto coal + limestone
16,000 x $62 = $992,000 for coal
16,000 x 38 x .62 = $376,960 for limestone
Total cost = 992,000 + 376,960 = $1,368,960 annually

Annual cost with low sulphur coal and no limestone
16,000 x 97 = 1,552,000 for coal.

If it were practical to use Minto coal in terms of corrosion (the limestone might make the corrosion manageable) the cost would be less than for low sulfur coal at $97. There is serious doubt as to whether it would be practical to ship such a small quantity of coal from Hampton Roads or Norfolk. Such small shipments are normally handled by attaching a coal cars to a freight train.

WESTERN CANADIAN COAL

Western Canadian coal can compete with U. S. coal as evidenced by the fact that it is being used in Europe. The question of deliveries of Western Canadian coal to the Maritimes has been discussed with Shell's coal people, Fording Coal Luscar and others. It is clear that a lot of effort would be involved in arranging such a small shipment. These people are so busy developing markets in the Pacific Rim countries and Europe that it is difficult to induce them to spend much time talking about small orders so far away. For this study it has been assumed that a Western Canadian supplier would meet the U.S. low sulfur coal price after considering heating value etc.

If one of the Maritime Utilities were to cooperate in the development of a coal storage and distribution center (to serve industries and plants such as Gagetown) at say Point Tupper or Colsen Cove, the situation would be quite different. The distribution center together will self unloading carriers for delivery by water should make US coal as readily available in the Atlantic Provinces as it is in Ontario. Western Canadian low sulfur coal could also be handled by such facilities.

DEVCO COAL WITH LIMESTONE

The Devco coal used at CFB Gagetown has been costing from $80 to $90 per tonne. The sulfur level is about 3%. The annual cost with a Ca/S ratio of 3 would be:

16,000 x $85 = $1,360,000 for coal
16,000 x $38 x .31 = $189,756 for limestone
Total = $1,360,000 + $189,756 = $1,549,756 annually

This is about the same as the estimated cost of low sulphur coal from either USA of Western Canada. With the cooperation of the railroad, Devco should be able to match the low sulphur coal despite a possible future limestone requirement if the low sulfur coal actually cost $97/tonne. An interesting comparison is the price being paid by a pulp and paper mill at Thunder Bay of $50 Cdn/tonne for US coal with just over 1% sulfur. That coal travels about as far as would US coal to the Maritimes. The quantity is considerably greater but it is an indication of the potential for boiler fuel cost reduction if there were to be a substantial flow of coal to the Maritimes together with storage and distribution facilities

The reality is that because of the desire of the Nova Scotia government to use local coal and develop Sable island Gas, U. S. or Western Canadian coal are not likely to be used unless electric utility demand develops to the point where Nova Scotia and NewBrunswick cannot meet it.

A further consideration is the possibility of the development of a new underground mine at Springhill. This was discussed with John Smith, the CEO of Novaco. According to John, it is unlikely that Novaco will be in a position to supply CBF Gagetown. The delivered price of the 1982/83 supply from a surface mine was $64.90/tonne. The Calorific value is about 85% of that of Devco or good US coal. The sulfur level is 2%. If a deeper mine is developed, the quality may be better.

LOWER Ca/S RATIOS

If improved techniques for limestone injection with low

NOx burners can reduce SOx emissions significantly with a Ca/S ratio of 2, the economics improve significantly. Coal with 3% sulphur requires 0.2018 tonnes of limestone per tonne of coal.

The annual cost of limestone at a Ca/S ratio of 2 and 3% sulphur coal would be 16,000 x 38 x 0.2018 = $122,694. Assuming $7 per tonne premium for low sulfur coal, the annual coal cost differential due to burning low sulphur coal would be $112,000. Given the uncertainties as to coal prices it cannot be said whether 3% sulfur US coal with limestone injection at a Ca/S ratio of 2 would be more or less costly than burning low sulphur coal. It would be necessary to negotiate prices before making a decision. If they can negotiate satisfactory freight rates or use self unloading bulk carriers, Devco should be able to compete with low S US coal if the Ca/S ratio is 2.

Coal type	GJ/tonne	%S	%Ash	Ca/S	Annual cost. ($000)		
					Coal	Limestn.	Total
EASTERN CAN	33.0	3.0	10.	3.0	1,360.	189.	1,550.
EASTER CAN	33.0	6.0	22.0	3.0	992.	337.	1,369.
EASTERN U.S.	33.0	3.0	10.0	3.0	1,440.	189.	1,629.
EASTERN U.S.	33.0	0.5	10.0	3.0	1,552.	000.	1,552.
WESTERN CAN	33.0	0.5	10.0	3.0	1,552.	000.	1,552.
EASTERN CAN	33.0	3.0	10.0	2.0	1,360.	123.	1,483.

(While there would be differences in ash and heating value, these have been assumed to be the same except for Minto coal ash to simplify the comparision)

POTENTIAL UTILITY USE

Assuming a Ca/S ratio of 2, 2% sulfur coal and $40/tonne limestone, the cost for limestone (ignoring the capital and operating costs of the injection system) would

contribute about $2/MWH or 0.2 cents per kwh to the cost of electricity from the plant using the limestone.

In 1981 Eastern Canadian Utilities produced 110,000,000 MWH of electrical energy of which 37,247,000 MWH was from coal. Assuming a Ca/S ratio of 2 and a sulfur level in the coal of 2%, the annual cost would be 37,247,000 x 2 = $74,494,000. The combined total generation of those provinces which burn coal, from all sources in 1981 was about 124,554,000 MWH. 74.96/125 = $0.60/MWH or .06 cents per KWH.

LOW CAPACITY FACTORS AND S LEVELS

The advantages of limestone injection visa vis wet scrubbing are greatest when capacity factors and sulfur levels are low. Capacity factors and S levels for Canadian stations vary a good deal among regions. Significant quantities if coal with 1.5 to 1.7 % S; and 2.5% S are used for electrical generation in low capacity factor stations.

The conclusion is that this technology does have important potential for Canadian Utilities if results in terms of SOx reduction at a Ca/S ratio in the 2 to 3 range are as anticipated and slagging or fouling proves to be manageable. Limestone injection with low NOX burners could enable Canada to be seen to be its share of acid rain control without installing wet scrubbers. The economics of wet scrubbers are not at all good with low capacity factor operation.

EUROPEAN EXPERIENCE

An authoritative paper presented in Dallas in November 1982 indicates savings compared with the wet FGD approach ranging from 15% at 6,000 operating hour/year to 70% at 1,000 hours/year for the 700 MW unit using 1% S coal. These figures should be confirmed within a year because by then a

fully equipped 700 MW unit will have been in operation for some months. The results depend on the coal characteristics and on the boiler characteristics. A good deal remains to be learned.

ATLANTIC CANADA

If a nominal reduction is SOx emmissions is sought, the technology will be usefull in Atlantic Canada with higher S coals and high capacity factors. The technology has good potential for Western Canada if SOx reductions are sought despite the low S coal being used.

APPENDIX 1

Ca/S Ratio Versus Limestone Requirement

Ca/S MOLE RATIO	% S by WT. in COAL	% CaCO3 by WT in LIMESTONE	LB or KG LIMESTONE PER LB or KG COAL
2.000	0.50	90.00	0.0347
2.000	1.00	90.00	0.0694
2.000	1.50	90.00	0.1040
2.000	2.00	90.00	0.1387
2.000	2.50	90.00	0.1734
2.000	3.00	90.00	0.2081
2.000	3.50	90.00	0.2427
2.000	4.00	90.00	0.2774
2.000	4.50	90.00	0.3121

Ca/S MOLE RATIO	% S by WT. in COAL	% CaCO3 by WT in LIMESTONE	LB or KG LIMESTONE PER LB or KG COAL
2.500	0.50	90.00	0.0433
2.500	1.00	90.00	0.0867
2.500	1.50	90.00	0.1300
2.500	2.00	90.00	0.1734
2.500	2.50	90.00	0.2167
2.500	3.00	90.00	0.2601
2.500	3.50	90.00	0.3034
2.500	4.00	90.00	0.3468
2.500	4.50	90.00	0.3901

MOLE RATIO	by WT. in COAL	by WT in LIMESTONE	LIMESTONE PER LB or KG COAL
3.000	0.50	90.00	0.0520
3.000	1.00	90.00	0.1040
3.000	1.50	90.00	0.1561
3.000	2.00	90.00	0.2081
3.000	2.50	90.00	0.2601
3.000	3.00	90.00	0.3121
3.000	3.50	90.00	0.3641
3.000	4.00	90.00	0.4161
3.000	4.50	90.00	0.4682

READY
>

APPENDIX 1

Ca/S MOLE RATIO	% S by WT. in COAL	% CaCO3 by WT in LIMESTONE	LB or KG LIMESTONE PER LB or KG COAL
3.500	0.50	90.00	0.0607
3.500	1.00	90.00	0.1214
3.500	1.50	90.00	0.1821
3.500	2.00	90.00	0.2427
3.500	2.50	90.00	0.3034
3.500	3.00	90.00	0.3641
3.500	3.50	90.00	0.4248
3.500	4.00	90.00	0.4855
3.500	4.50	90.00	0.5462

Ca/S MOLE RATIO	% S by WT. in COAL	% CaCO3 by WT in LIMESTONE	LB or KG LIMESTONE PER LB or KG COAL
4.000	0.50	90.00	0.0694
4.000	1.00	90.00	0.1387
4.000	1.50	90.00	0.2081
4.000	2.00	90.00	0.2774
4.000	2.50	90.00	0.3468
4.000	3.00	90.00	0.4161
4.000	3.50	90.00	0.4855
4.000	4.00	90.00	0.5549
4.000	4.50	90.00	0.6242

Ca/S MOLE RATIO	% S by WT. in COAL	% CaCO3 by WT in LIMESTONE	LB or KG LIMESTONE PER LB or KG COAL
4.500	0.50	90.00	0.0780
4.500	1.00	90.00	0.1561
4.500	1.50	90.00	0.2341
4.500	2.00	90.00	0.3121
4.500	2.50	90.00	0.3901
4.500	3.00	90.00	0.4682
4.500	3.50	90.00	0.5462
4.500	4.00	90.00	0.6242
4.500	4.50	90.00	0.7022

APPENDIX 2

Tonnes Limestone/MWH — Assume 0.34 Tonnes Coal/MWH — 27.8 million BTU/tonne coal

% Sulphur	.5	1	1.5	2	2.5	3	3.5	4	4.5
Ca/S Ratio									
2	.01156	.023596	.03536	.047158	.058956	.070754	.0816	.094316	.106114
2.5	.014722	.02924	.0442	.058956	.073678	.088434	.103156	.117912	
3	.01768	.03536	.053074	.070754	.088434	.106114			
3.5	.020638	.041276	.061914	.082518	.103156				
4	.023596	.047158	.070754						
4.5	.02652	.053074							

Note - Electricity costs in Canada range from about $20/MWH (2 cents/kwh) to $30/MWH (3 cents/kwh)

Limestone Component of Electricity Cost $/MWH

Tonne/MWH	.01	.02	.03	.04	.05	.06	.07	.08	.09	.1
$/Tonne										
40	.4	.8	1.2	1.6	2	2.4	2.8	3.2	3.6	4
50	.5	1	1.5	2	2.5	3	3.5	4	4.5	5
60	.6	1.2	1.8	2.4	3	3.6	4.2	4.8	5.4	6
70	.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7
80	.8	1.6	2.4	3.2	7.2	4.8	5.6	6.4	7.2	8
90	.9	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.1	9
100	1	2	3	4	5	6	7	8	9	10

G. A. ROBB ASSOCIATES
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APPENDIX 3

INFORMATION ON LIMESTONE AND OTHER CALCIUM BASED PRODUCTS AVAILABLE FROM HAVELOCK LIME, HAVELOCK, NEW BRUNSWICK

Havelock is within trucking distance of CFB Gagetown. The firm has a good reputation. They are equipped to crush and screen limestone for delivery by dump truck. They are also equipped to dry and size crushed limestone for pneumatic handling using screens for courser material and an air classifier for fine material.

They estimate that the 100 mesh or less material contains at least 50% 200 mesh or less material. The equipment they have now can not produce pure 200 mesh or less material. To produce 100 or less they use a grinder followed by an air classifier. They say that to produce pure 200 or less material, a $500,000 new air classifier would be required. They have undertaken to have the 100 or less material tested to find out how much 200 or less

mat:rial it contains.

Calcium oxide is available at about $60 per ton plus $14 per ton transportation- ie. $74 per ton. Calcium hydroxide is now price at about $69 per ton plus tranportation- ie $83 per ton. In the case of calcium hydroxide, 98% passes a 200 mesh screen and most is smaller.

Before the oil price increase, calcium hydroxide was priced at $20 per ton. The cost of either calcium oxide or calcium hydroxide is largerly due to the price of oil for the kiln used for calcining. If a cheaper fuel could be found the material would cost less.

Following are prices as of early 1982:

CRUSHED LIMESTONE SCREENED BUT NOT DRIED

PARTICLE SIZE	MATERIAL COST $/METRIC TON	TRANSPORTATION COST $/METRIC TON
1.25" OR LESS	$9.20-$9.60	$8.80
1.25" TO 0.75"	" "	"
0.75" TO O.25"	" "	"
0.625" TO 0.25"	" "	"
0.50" TO 0.25"	" "	"
LESS THAN 0.25"	$5.60	"

None of the above can be handled pneumatically

Less than 0.25" contains dust - a problem when wet

HIGH CALCIUM SCREENED AND DRIED - DELIVERED BY TANK TRUCK EQUIPPED FOR PNEUMATIC UNLOADING TO 60 FT UP

MESH AND PARTICLE SIZE		MATERIAL COST	TRANSPORTATION COST TANK TRUCK
PASSES max	RETAINED min. size particle		
6 MESH	16 MESH	$20.20	$14.00 (COURSE NO DUST)
16 OR LESS		15.60	14.00 (INCLUDES DUST)
16	100	17.60	14.00
100 OR LESS		23.80	14.00 (ALL DUST)
Calcium oxide		$69	14
Calcium Hydroxide		$70	14

EACH TRUCK DELIVERS 30 TONS

Note - The 16 or less dried high calcium material costing $15.60 per ton for material and $14 per ton for delivery or $29.60 per ton delivered is mostly dust and should be

suitable

Havelock lime supplies pulp and paper mills, agriculture (lime for increasing soil alkalinity for checken feed etc.) and other markets. It is a locally owned family firm employing a good many people. Equipment such as tank trucks is quite modern.They have a kiln for calcining, facilities for drying and screening etc. The road between Havelock and CFB Gagetown is good and the distance reasonable

Mr. Gordon Thomas of Fredricton is an agent for Havelock Lime and has helped Mr. Pollitt. Both Mr. Thomas and the management of Havelock lime feel we would be better off using dried material which can be handled pneumatically.

At this stage and for the experimental period there is a case for dealing only with Havelock lime. If, after the experimental period is over, an alternative could be found, it might be considered if costs could be reduced.

APPENDIX 4

HAVELOCK LIME WORKS LTD.
P.O.Box 59, Havelock, N.B. E0A 1W0
PHONE: 534-2311 TELEX: 014-2651

May 28, 1982

G. A. Robb
1855 Beattie Ave
Ottawa, Ontario
K1H 5R7

Dear Mr. Robb,

We are pleased to enclose a sieve analysis on our 200 mesh material which is marketed as lime dust.

We enclose our brochure explaining some of our other limestone products.

Yours truly,

J. L. Murray
General Manager

JLM:kb
enc.

SIEVE ANALYSIS LIME DUST

May 28, 1982

Size	Wt %
+100 mesh	2.7
-100+200 mesh	4.7
-200+230 mesh	3.1
-230+270 mesh	7.3
-270+325 mesh	3.2
- 325 mesh	79.1
	100.1